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University of Nebraska-Lincoln, jmwarner_05@hotmail.com

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PRODUCTION AND ECONOMIC EFFICIENCIES OF INTENSIFIED COW-CALF
PRODUCTION MANAGEMENT SYSTEMS

by

Jason M. Warner

A DISSERTATION

Presented to the Faculty of
The Graduate College at the University of Nebraska
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Under the Supervision of Professors Richard J. Rasby and Terry J. Klopfenstein

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PRODUCTION AND ECONOMIC EFFICIENCIES OF INTENSIFIED COW-CALF
PRODUCTION MANAGEMENT SYSTEMS

Jason M. Warner, Ph.D.

University of Nebraska, 2015

Advisors: Richard J. Rasby and Terry J. Klopfenstein

The objective of four experiments conducted was to evaluate production and economic efficiencies of intensified cow-calf production management systems. The first experiment tested the effect of calf age at weaning on cow and calf performance and feed utilization at 2 locations. Body weight change from early to conventional weaning time was greater for early-weaned cows. Cow BCS and conception rates were not impacted by weaning. Calf BW at conventional weaning time was greater for conventionally-weaned calves than early-weaned calves at ARDC, but greater for early-weaned than conventionally-weaned calves at PHREC. Calf ADG per unit of total feed energy intake was greater for nursing pairs at ARDC, but not different between early- and conventionally-weaned pairs at PHREC indicating early-weaning may have minimal effect on reducing feed energy requirements. In Exp. 2, the effect of post-weaning management system and calf age at weaning was evaluated on growing and finishing performance, carcass characteristics, and economics of calves produced from an intensively managed cow-calf system. During growing, fast-track cattle had improved

DMI and ADG. Finishing DMI, ADG, HCW, and marbling were greater for slow-track cattle at the same 12th rib fat thickness. Breakeven was similar and profitability greater for fast-track. Weaning age had minimal impact, but post-weaning management influenced subsequent performance and economics demonstrating the value of alternative management systems. The third experiment studied supplementation of ethanol by-products and low-quality forages to cow-calf pairs grazing smooth brome grass pastures as a method to reduce grazed forage intake. Supplementation replaced approximately 40% of grazed forage intake suggesting that ethanol co-products and low-quality forages can replace grazed forage intake allowing for increased stocking rate without impacting animal performance. An analysis of profitability of intensively managed cow-calf systems utilizing distillers grains and crop residues and the economic sensitivity of profitability to changes in feed costs, feeder cattle prices, replacement female costs, and reproductive rates was conducted in Exp. 4. Greater returns were projected as weaning percentage increased, but the economic feasibility and extent of positive returns of such a system will be dependent on price relationships for feed and calves and cowherd reproductive performance.

Acknowledgments

Henry Ford once said “Thinking is the hardest work there is, which is probably the reason so few engage in it”. During my graduate career, I have come to understand how true this quote is. Of all the lessons I have learned, the ability to think critically is most important. Completing my Ph.D. has been without question the most challenging and rewarding endeavor, and the opportunities and trials I have encountered have only positively influenced me as a person.

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Introduction

Historically, grazing has been the most economical method of utilizing forages for beef cattle. Consequently, conventional cow-calf production operations in all areas of the world have evolved as extensively managed systems with a dependency on forages for grazing during at least a portion of the year. Minimizing the use of harvested forages and feeds to meet cowherd nutrient requirements and maximizing grazing days has been a common objective for most cow-calf enterprises and is usually most economical when the price of grass is low relative to other feeds.

In the event that traditional forages become limited or unavailable, other feeds must be utilized to maintain the beef cow-calf enterprise in an intensively managed (confinement) system. In recent years, many events within agriculture have influenced the availability of traditional forages for pasture and hay production. The price of grain commodities, chiefly corn, is one such variable that has impacted land values and initiated the conversion of traditional forage acres to grain crop production. This has occurred mainly in the Midwest and Northern Great Plains regions. In these areas, increased corn and ethanol production has resulted in a greater supply of distillers grains and corn residue which can be used by intensively managed cow-calf systems requiring a forage and source of protein and/or energy when complete diets are fed. Logically, intensive cow-calf systems compliment those areas focused on grain production.

At the time of this writing the beef cattle industry is in unprecedented times. Land use and real estate market dynamics influenced by variable commodity prices, the recession of a historic drought and associated easement in feed prices, and industry expectations for cowherd expansion have created strong interest in intensified cow-calf

production systems as a viable production model. Feeding cows in intensive management is not new, as most of the research establishing the fundamentals of beef cow nutrition was conducted in a pen setting. However, few have evaluated intensive cow-calf management from the basis of a complete production system, as has been done with conventional cow-calf production. Unanswered questions persist regarding the influence of management practices such as calf weaning age and limit-feeding on cow and calf performance. Post-weaning management of calves reared in intensive systems from birth until weaning has not been widely studied nor has supplementing to replace forage intake in partially-confined cows. Indeed, many production variables influence economics. The concepts and principles often considered true for cow-calf production in conventional systems may change in intensified systems. The objective of this dissertation is to evaluate intensive cow-calf production systems from the perspective of calf management systems through 205 day weaning and post-weaning systems through harvest, cow supplementation programs to reduce forage intake, and economics. Previous research regarding these practices is summarized in the following review.

Literature Review

The Beef Cow-Calf Industry

For the beef cattle industry to produce a high-quality protein for human consumption, profitable cow-calf systems are essential. Because the world-wide human population is forecast to expand, the demand for beef is anticipated to grow concomitantly, and productive cow-calf operations will be necessary to supply that demand. Expected demand growth presents a challenge and opportunity for the industry. Given beef cow operations typically require a substantial land base, the concept of increasing beef production with systems on fewer resources would be advantageous. As discussed by Miller et al. (2001), profitable cow-calf operations strive to decrease production expenses while optimizing reproduction. The economics of cow-calf production would likely change if costs associated with land resources decreased.

As of January 1 2015, the United States beef cow inventory was 29.7 million cows, 2% larger than 2014 (USDA, 2015). However, the cow inventory decreased by 15 million cows from 1975 to 2014. Texas (4.18 million), Oklahoma (1.9 million), Missouri (1.88 million), and Nebraska (1.79 million) contained the largest cow inventories by state as of January 1 2015, which equates to 33% of the national herd (USDA, 2015). Other states with extremely diverse environments maintain relatively large populations of beef cows (Montana = 1.5 million; Florida = 916,000) demonstrating cow-calf production occurs throughout most regions of the United States, unlike cattle feeding which is concentrated in the Midwest and Great Plains. This inventory of cows, and subsequent source of calves, is critical for supplying the feeding industry both in Nebraska and across the U.S.

Historically, cow-calf production is a by-product of land ownership and does not represent the primary source of income for most operations (Troxel et al., 2007). A large proportion of cow-calf operations contain small herds. In 2012, 729,000 operations maintained beef cows in the U.S. with 581,000 enterprises having ≤ 50 cows, but representing 28% of the total cow inventory (USDA, NASS). Likewise, only 4,230 operations maintained ≥ 500 cows, 9% of the inventory. This has important ramifications for the entire beef industry, because small operations often cannot capture production efficiencies as well as large operations. Certainly, the beef cattle industry differs from swine or poultry because the beef industry is not vertically integrated and is comprised of a large number of cow-calf producers with different management systems controlling feeder calf production.

Current Beef Industry Trends and Issues

Cattle Inventory

Extensive discussion has occurred recently within the industry regarding the cattle inventory. Cattle inventories have decreased over time for various reasons, notwithstanding the fact that the industry has become more efficient and can produce more beef with fewer animals (Capper, 2011). Many have questioned the economic ramifications if the cattle industry continues to contract. Cow numbers increased by approximately 650,000 cows or 2% nationwide from 2014 to 2015, despite the industry generally contracting during the previous four decades (USDA, 2015). This minor indication of expansion is likely due to increased female retention for breeding and decreased beef cow harvest, permitted by recent improvements in precipitation across cow-calf production areas. However, changes in beef cow inventories vary by

geographical region and appear to be influenced by land use practices. As reported by MacDonald et al. (2014), the U.S. beef cow herd shrunk by about 2.4 million cows between 2006 and 2011. Interestingly, nearly 50% of that inventory reduction occurred in the Midwest and Northern Great Plains states including Nebraska, Kansas, Missouri, Iowa, and South Dakota. This reduction in these areas may be related to changes in the availability of traditional forages necessary for cow-calf production.

Land Use Trends and Economics

Cereal grain market prices have fluctuated during the past 2-3 years, but corn and soybean prices have generally been high throughout the last decade as a result of biofuel industry demand (Wright and Wimberly, 2013). Corn prices increased two-fold from 2006 to 2011. The cattle industry has observed an accelerated conversion of grassland to cropland throughout the major corn production areas of the United States. Data from Wright and Wimberly (2013) indicated grassland transformation to crop production between 2006 and 2011 occurred predominantly in the eastern halves of North and South Dakota and similar developments were observed in Nebraska. South Dakota and Iowa contained areas with the highest concentration of land use change from grassland to corn/soybean production, with 182,513 and 152,161 hectares converted in those states, respectively. The total net decrease in grassland during this time period was over 526,091 hectares in the entire region encompassing North Dakota, South Dakota, Nebraska, Minnesota, and Iowa. Annually, conversion rates averaged between 1 and 5.4% per year (Wright and Wimberly, 2013). Available risk management programs such as federal crop insurance and disaster relief are plausible reasons producers may convert grassland to cropland, aside from grain price levels. The challenge for cattle producers is

that in many instances, once grasslands are tilled for crop production, it is difficult for those lands to be reestablished for pasture or hay production, particularly if fences and watering sources are removed.

A scarcity of pasture and land for hay production leads to increased prices during periods of high demand. Low cattle inventories have led to record high cattle prices resulting in increased demand for pasture and other grasslands, particularly now as recent interest in expanding the cowherd has grown due to improved moisture conditions in most cow-calf production areas. Pasture rental fees in Nebraska have increased by approximately 40% on average from 2006 to 2012 (MacDonald et al., 2014). In 2014, pasture rental rates (\$ per cow-calf pair per month) averaged \$46 across all regions of Nebraska (range of \$32 to \$60) (Jansen and Wilson, 2014). Likewise, the same authors reported that the average value of tillable and non-tillable grazing land in Nebraska increased by 14 and 24%, respectively, between 2013 and 2014. Similar trends can be found in neighboring states. A 2015 Iowa survey (Plastina et al., 2015) demonstrated pasture rental fees averaged \$22 per AUM or \$34 per pair per month, up from \$10.70 per AUM in 2005. In South Dakota, cash rental fees for pasture/rangeland have increased between 35 and 64% depending on region between 2009 and 2014 (Janssen et al., 2014). These data provide evidence that pasture rental fees have strengthened in areas where pasture acreage has concomitantly decreased.

Changes in Feed and Forage Production and Availability

Forage Production Trends

Nationally, total area harvested for all hay production decreased about 1.8 million hectares from 2005 to 2015 (USDA, NASS). During the same time period, total hay

production in the U.S. decreased 9.7 million metric tons. The national average price for all hay increased approximately 85% (\$96 to \$178/ton) during the last 10 yr (USDA, NASS). In Nebraska, total hay production declined about 816,000 metric tons from 2002 to 2012. In Iowa and South Dakota, total hay production has shrunk 2.0 and 1.6 million metric tons, respectively, from 2002 to 2012. Regarding alfalfa hay, total acres harvested in the U.S. declined 1.6 million hectares, while alfalfa hay production decreased 12.7 million metric tons (USDA, NASS). During the same time period, U.S. corn production increased 1.7 billion bu, and area harvested grew by 7.7 million hectares. This increase in corn production (1.7 billion bu) equates to 11.8 billion kg (DM) of residue produced. These evolvments in hay and corn grain production reflect the conversion of grassland to cropland in certain areas and validate that traditional forage resources (pasture, hay land) are diminishing, but forage derived from crop residue is expanding. The possibility of removing a portion of the residue for forage becomes more evident as corn and residue production continues to increase, because high amounts of residue can impede crop establishment in high production areas (Wienhold et al., 2013).

The Ethanol Industry and Production of Co-Products for Feed

The dry-milling ethanol industry has grown in recent decades in response to domestic and foreign demand for renewable fuel (Klopfenstein et al., 2008). Recent data (NE Ethanol Board, 2015) demonstrates the annual production capacity within Nebraska is nearly 2 billion gallons. As of 2012, over one hundred seventy ethanol plants were operating nationally with twenty-four plants located in Nebraska. Nebraska ranks second in national ethanol production (NE Ethanol Board, 2015).

The starch content of corn is nearly 70%, and this nutrient is fermented to produce ethanol (Klopfenstein et al., 2008). The remaining nutrients of corn are recovered in co-products. Dry-milling ethanol plants generate varying forms of co-products which can be broadly referred to as distillers grains (Milton, 2001). However, differences in composition and moisture content warrant differentiation among specific products (Lardy, 2007). Ethanol co-products include wet distillers grains plus solubles (WDGS), modified distillers grains plus solubles (MDGS), dried distillers grains plus solubles (DDGS), and corn condensed distillers solubles (CCDS) (Tjardes and Wright, 2002). Therefore, the relative concentrations of crude protein (CP), fiber, fat, and minerals are increased approximately three-fold in distillers grains plus solubles relative to corn grain (Erickson et al., 2010). The nutritional profile of co-products makes them attractive for use in ruminant diets (Ham et al., 1994; Cao et al., 2009). Due to the growth of Nebraska's ethanol industry, cattle producers within the state theoretically have access to approximately 5 million metric tons (as-is) of co-products annually.

Feeding Cows in Confinement as a Management System

By definition, confine means to hold within a location (Merriam-Webster, 2002). Therefore, beef cattle have been confined for production since the end of the open range era. The extent to which cattle are confined varies from large pastures spanning several thousand hectares to very small pens. Maintaining beef cows within a confined drylot pen setting (intensive management) is not novel, and historically has been most common during winter when forages for grazing are dormant (Miller et al., 2007). Feeding cows and their offspring in intensive management throughout the traditional summer or autumn grazing season is less typical, but may be warranted if forage for grazing is unavailable

(Farney et al., 2014). As noted by Anderson and Boyles (2007), the advantages of an intensively managed system are numerous and may include: increased control of herd health and management, ease of implementation for estrous synchronization and artificial insemination, reduced calf stress at weaning, increased beef production per unit of land, and may enable recovery for damaged rangeland or pasture. Challenges are: increased labor and equipment needs, faster depreciation of facilities and equipment, increased management of nutrition and herd health, greater risk of animal injury or disease, and environmental challenges (i.e. dust, mud, etc.).

Original research on feeding beef cows throughout lactation in intensive management aided in estimating cow energy requirements (Neville and McCullough, 1969; Neville, 1974) and energetic efficiencies of milk and beef production (Schake and Riggs, 1975). Early trials in Kansas evaluated calf weaning age (McKee and Fink, 1978), supplemental creep feeding (Kimple et al., 1977), and the use of ionophores in diets for early-weaned calves (Busby et al., 1980) as management techniques for spring-calving cows and calves maintained in intensive management during summer. Much attention recently has been directed towards studying beef cow nutrition, specifically during late-gestation or early-lactation, with cows in drylot or intensive management systems. This is beneficial because in a pen-setting, intake can be more accurately measured than grazed forage intake can be estimated by any technique (Patterson et al., 2006; Coleman et al., 2014). Data indicate nutrition programs for beef cows can be formulated with various ingredients including alfalfa hay (Miller et al., 2007), whole shelled corn (Loerch, 1996; Schoonmaker et al., 2003), processed corn (Tjardes et al., 1998), ethanol co-products (Shike et al., 2009; Faulkner et al., 2012; Anderson et al., 2013b; Faulkner et al.,

2013), sugar industry co-products (Jenkins et al., 2015), sunflower screenings (Anderson, 2002), food waste (Walker et al., 2004) and poultry manure (Rossi et al., 1999). Current biological and economic data on feeding cows and their progeny throughout the entire production cycle are limited because most trials end at the start of summer grazing. Data collected over multiple years in North Dakota from one of few cowherds maintained in intensive management as a production system indicate little difference in cow or calf performance, but production costs were \$22 higher per cow-calf pair per year than a conventional system (Anderson et al., 2013a).

Regarding management, several concepts need addressing when maintaining cows and calves in intensive systems. Fundamental is that the cow's nutrient requirements differ with stage of production, milk production level, age, body weight, body condition score, and environmental conditions (NRC, 1996). Understanding both the animal's nutritional needs and the nutrient composition of feed ingredients are essential for developing balanced diets. If lactating cows are fed in intensive management, supplying additional feed for the calf is necessary because calves will eat alongside their dams at a young age (Jenkins and Rasby, 2014). Hollingsworth-Jenkins et al. (1995) reported that nursing calves (BW = 130-178 kg) consumed 1.1-1.5% of BW (OM basis) in forage while grazing native Sandhills range. Similar results were observed by Loy et al. (2002). Observations indicate cows consume meals aggressively when limit-fed, and calves may have little opportunity to ingest feed if fed with their dams. Therefore, providing supplemental feed that only calves may access (creep feeding) or early-weaning is commonly recommended (Anderson and Boyles, 2007; Rasby and Niemeyer, 2011). Creep feed intake was positively correlated ($r = 0.42-0.91$) with BW

for drylot calves (Lusby et al., 1976). Brahman and Romana Red-sired calves were approximately 30 kg heavier at 210-d weaning than calves not creep fed (Prichard et al., 1989). Creep-fed nursing steer calves grazing fescue pasture gained 32% more than calves not creep-fed before weaning, but early-weaned steers gained 0.72 kg per d more than nursing-steers (Myers et al., 1999). Early-weaning is often advocated for drylot production systems because calves convert feed to BW gain efficiently (Myers et al., 1999) and calves are easily trained to consume feed from a bunk.

Although not tested, typical recommendations for feed bunk space allotment for cows and calves in intensive management are 0.61 m per cow and 0.3 m per calf, or approximately 1 m total per pair (Farney et al., 2014; Jenkins and Rasby 2014). Interestingly, ADG and F:G were not improved by allotting greater than 0.15 m per steer when feedlot cattle (BW = 265 kg) were limit-fed (Zinn, 1989). Concerning other management, water is the most critical nutrient for all animals. Adequate water must be available to both cows and calves in intensive systems, as lactating cows will consume approximately 40 to 60 liters per d, depending on environmental conditions. Quigley (2001) noted that young calves (≤ 60 d of age) consumed 2.5 liters per d of water and that intake increased exponentially as air temperature increased. Considerations for minimizing environmental stress are warranted for cows and calves in intensive management. The use of wind protection and bedding in winter and shade in summer may help animals adapt to severe conditions and reduce economic losses (Mader, 2003).

Systems for Estimating Beef Cattle Nutrient Requirements

Energy

The origins of nutritional energetic systems can be dated to the 1400s, after which time the fundamental concepts of O₂ and CO₂ exchange and heat production were established, ultimately leading to the development of the laws of thermodynamics in the 1840s (Ferrell and Oltjen, 2008). Establishing the laws of thermodynamics was foundational for the advancement of nutritional energetics and the relationship that metabolizable energy (ME) is the sum of retained energy (RE) plus heat energy (HE). Throughout the latter part of the 1800s and early 1900s, substantial attempt was made by researchers to further understand gas exchange and heat production. Concurrently, effort was placed on developing systems for evaluating the energy content of feeds relative to energy expenditures and requirements. An excellent review of the development of net energy systems for beef cattle was published by Ferrell and Oltjen (2008) which was used as the basis for this discussion.

The physiological fuel values system (Atwater and Bryant, 1900) was based on ME values of carbohydrates, fat, and protein and is the basis for the total digestible nutrient (TDN) system. In this system, feedstuff energy values are ME values at maintenance intake. Feed TDN values are determined from estimates of the digestible components of feed: $\text{TDN} = \text{digestible crude protein} + \text{digestible fiber} + \text{digestible nitrogen-free extract} + \text{digestible ether extract} \times 2.25$. Requirements for TDN are calculated by summing TDN requirements for maintenance, growth, lactation, and other functions. A critical limitation with the TDN system was that TDN values for forages and concentrates were not additive in ruminant diets. The TDN values for feeds differ when used for varying animal functions, partially attributed to increased CH₄ production during forage digestion. Loss of heat from fermentation, alterations in intake from

changes in digestibility, and varying end products of fermentation all lend to the non-additivity of forages and concentrates in the TDN system and are realized in the ability of the diet to be digested and metabolized.

It was acknowledged that representing the energy content of a feed as a single value proved inaccurate because the efficiency with which diet ME is utilized varies. Consequently, net energy (NE) systems were developed with ME as a point of initiation. Researchers at the University of California-Davis conducted comparative slaughter experiments (Lofgreen, 1965) with growing and finishing cattle, ultimately leading to the California Net Energy System (CNES; Lofgreen and Garrett, 1968). This system described energy requirements of beef cattle with two NE values for feeds and animal requirements, net energy for maintenance (NE_m) and net energy for gain (NE_g), recognizing that ME is used with different efficiencies for each function. Energy requirements for maintenance and production of breeding cattle were also developed from the CNES (NRC, 1976). The efficiency of ME use for lactation is similar to that for maintenance so requirements for lactation were represented in terms of NE_m . The efficiency of ME use for fetal and placental growth and maintenance was 13%, so requirements for pregnancy were also represented as NE_m .

The CNES utilizes a measured or estimated fasting heat production (FHP) as the foundation for estimating NE_m . Energy necessary for maintenance is determined as the MEI at which point $RE = 0$ or $HE = MEI$. By regressing between these two intake levels, NE_m was calculated. Net energy for maintenance requirements (Mcal per d) for beef cattle (steers, heifers, bulls, and cows) have been estimated as $0.077EBW^{0.75}$, with empty body weight (EBW) in kg (NRC, 1996). Data from British-based growing steers and

heifers in a non-stressed penned setting were used to develop NE_m requirements. Fundamental to the NE system is the concept that as intake increases beyond that required for maintenance, all of that energy is partitioned toward gain. The NE_g requirement is measured as the slope of the regression of RE on DMI, at two DMI levels (Ferrell and Oltjen, 2008). Graphically, the slopes of the two lines for NE_m and NE_g will be different. The slope is greater for NE_m which suggests that energy is used with a greater efficiency for maintenance than for gain. This is logical, because energy will be used for maintenance functions in the body first before energy is partitioned for gain. The primary advantage of this system over the TDN-based system is that it allows one to determine how much to feed cattle based on the energy level in the diet and desired rates of gain, or one can calculate how much cattle should be gaining if intakes are known.

Protein

The prior version of the NRC (NRC, 1984) contained beef cattle requirements relative to CP. The metabolizable protein (MP) system also estimates protein requirements of beef cattle, and was adopted by the NRC approximately 20 yr ago (NRC, 1996). Two reasons have been cited defending the use of the MP system versus the CP system. During the time of adoption by the NRC (mid-1990s), a greater abundance of data was published regarding microbial crude protein (MCP) production and rumen undegradable protein (RUP), providing more accurate estimations. Also, the CP system is erroneously premised on the assumption that all feeds undergo similar protein degradation in the rumen (NRC, 1996). Resembling the advancement made by adopting the NE system, the movement from a CP to a MP system represented a significant increase in the understanding of beef cattle protein requirements. The MP system

differentiates between the protein requirements of the host animal and that of the rumen microbiome (Patterson et al., 2006). The system recognizes that feedstuffs differ with regard to rumen degradability of protein. Protein supplying nitrogen to the rumen, which is incorporated into microbial crude protein (MCP), is termed rumen degradable protein (RDP). Microbial crude protein may furnish 50 to nearly 100% of the MP required, depending on the degradability of dietary protein (NRC, 1996). Efficient rumen digestion and utilization of feed is dependent on RDP intake (Köster et al., 1996). Consumed protein that does not undergo rumen degradation is digested and absorbed at the small intestine and referred to as rumen undegradable protein (RUP). This protein is commonly termed “escape” or “bypass” protein. Metabolizable protein represents the true protein absorbed by the animal, and is the summation of MCP and RUP (NRC, 1996).

The MP system requires an approximation of MCP synthesis because MCP is fundamental for determining MP supply and RDP requirements, and dietary energy intake controls MCP production (Patterson et al., 2006). Mathematically, MCP production (g per d) is the product of TDN intake (kg per d) and microbial efficiency (g per kg), or it is simply equivalent to RDP intake (g per d). Microbial efficiency represents the rate of which energy is converted to MCP (Patterson et al., 2006). For microbial efficiency, 13 g MCP per 100 g of TDN intake is a generalization made by the NRC (1996) model, but is inappropriate for instances of low and high diet digestibilities. When highly-digestible grain-based diets are fed, decreased rumen pH slows microbial turnover and decreases the efficiency with which protein is converted to MCP. Conversely, microbial efficiency is hindered when low-quality forages are fed because

decreased rate of passage also slows microbial turnover (NRC, 1996). Suitable use of the MP system requires an accurate estimate of microbial efficiency because of the relationship between MP supply and RDP requirement.

The rumen degradable protein requirement is essentially equal to the amount of MCP produced. This is assuming that the loss of ammonia from the rumen due to flushing to the duodenum or absorption through the rumen wall is equal to the amount of recycled nitrogen (NRC, 1996). A deficiency of ruminal ammonia encourages recycling and an excess encourages absorption from the rumen. Data from Wilkerson et al. (1993) demonstrated that the maintenance requirement for MP of growing calves was 3.8 g MP per kg BW^{0.75} which was supported by nitrogen balance data from Susmel et al. (1993). This value is used as the published maintenance requirement for MP for all cattle (NRC, 1996).

Factors Influencing Beef Cow Nutrient Requirements

Beef production requires substantial energetic inputs throughout the system. It has been frequently quoted that 65 to 75% of the total energy requirements for beef production are directed towards maintenance (Ferrell and Jenkins, 1985). The cowherd uses approximately 70% of the total energy for beef production (Gregory, 1972; Klosterman and Parker, 1976), implying that nearly 50% of the entire energy required for beef production is used for meeting cow maintenance requirements. Clearly, if maintenance requirements were decreased in the cowherd, the result would be an improvement in biological efficiency of the entire system. Several factors contribute to maintenance requirements in the beef cow.

Stage of Production

Maintenance requirements increase as pregnancy advances. There is a direct relationship between gestational nutrient demands and calf birth weight (NRC, 1996). Calf birth weight can be influenced by dam nutrition, parity, heterosis, breed of sire and/or dam, environmental temperature, and sex (Ferrell, 1991). There is an exponential growth pattern for the fetus and placenta, so net energy requirements for gestation do not contribute significantly to overall energy requirements until late in gestation. Interestingly, the fetus is considerably larger than the placenta in near-term females, yet energy partitioned by placental and fetal tissues is not different (NRC, 1996). Ferrell et al. (1976) noted that ME is used for accretion in the uterus at 14% efficiency in Hereford heifers bred to Hereford bulls.

Lactating females have 20 to 30% higher maintenance energy requirements than nonlactating females (NRC, 1996). However, ME is used for maintenance and lactation at similar efficiencies, so requirements may be stated in terms of NE_m . Considering the fat, protein, and solids not fat content of milk is 4.0%, 3.4%, and 8.3%, 0.72 Mcal NE_m are required for each kg of milk produced (NRC, 1996). The increased energy requirement of lactation may be attributed to organ and tissue size and function (Smith and Baldwin, 1974). Those authors reported that lactation increased the size of vital organs (i.e. liver, mammary gland, lungs, rumen, abomasum) 20 to 35%. Similar data have been reported by Canas et al., 1982.

Level of Milk Production

While milk production in a beef female is very challenging to measure, it represents a critical aspect of maintenance requirements. Several groups have concerted efforts toward measuring milk yield (Williams et al., 1979; Marshall et al., 1984; Green

et al., 1991), but few data have been collected which define the length and shape of the lactation curve. Milk production is influenced by cow age, breed, genetic capability, diet, time of lactation relative to calving, and environment (NRC, 1996). Maximum milk production is variable, and values of 4 to 20 kg/d have been documented. Data suggest young females (2 to 3 yr of age) produce 15 to 25% less milk than mature cows. At wk 9 of lactation, the NE_m requirement, for milk production, for cows producing 14 kg/d is nearly three-fold greater than a female generating 5 kg/d (NRC, 1996). Many investigators have attempted to determine the extent to which maintenance is influenced by milk production level. Relative to cows with a medium (Red Poll \times Angus) or low (Hereford \times Angus) milk production potential, cows with greater levels of milk production (Milking Shorthorn \times Angus) had 12% greater maintenance requirements during both gestation and lactation (Montaño-Bermudez et al., 1990). This concurs with earlier work (Ferrell and Jenkins, 1984) suggesting that cattle capable of high levels of milk production have greater maintenance requirements, even while lactation is ceased. Interestingly, progeny of females with increased milk production levels had greater maintenance energy requirements during growing and finishing (Montaño-Bermudez et al., 1990). Given the influence of milk production level on maintenance requirements, a fundamental concept to improve system efficiency is to match the genetic capability of the cowherd to the environment in which they are managed.

Breed

Many studies have attempted to evaluate breed differences in maintenance requirements (NRC, 1996). Most have reported differences either between or among different breeds and validate that variability remains with maintenance requirements

chiefly due to the diversity of genetics, methodologies used, and experimental conditions. Relative to *Bos taurus* breeds (Angus, Hereford, Shorthorn, Charolais, Limousin), breeds of *Bos indicus* cattle (Africander, Barzona, Brahman, Sahiwal) have 10% lower maintenance requirements. Logically, crossbreds of *Bos taurus* and *Bos indicus* breeds would be intermediate. Dairy or dual-purpose *Bos taurus* breeds of cattle (Ayrshire, Brown Swiss, Braunvieh, Friesian, Holstein, Simmental) have approximately 20% greater energy requirements than beef breeds. Published data suggest that relative differences in maintenance requirements between breeds in mature animals are not different from that observed in growing animals (NRC, 1996). This would imply that a positive relationship is apparent between maintenance requirements and genetic potential for productive traits (i.e. growth rate or milk production) and this relationship exists for both growing and adult cattle. In nutritionally or environmentally prohibitive environments, animals with genetic potential for highly-productive traits may be challenged or at a disadvantage. Furthermore, correlated selection responses may result in a genotype by environmental interaction and selection pressure may result in a population of cattle uniquely adapted to a specific environment, but poorly adapted to different environments with limited ability to change to environmental constraints (NRC, 1996).

Body Weight

Maintenance energy expenditures vary with body weight. As noted by the NRC (1996) fasting heat production and NE_m is more related to a fractional power of EBW than to $EBW^{1.0}$. Empty body weight^{0.75}, normally referred to as metabolic BW, was historically implemented to provide proportionality on measurements of heat energy

made in species which vary in mature weight. Employing a fraction of EBW assists in scaling energy requirements for body weight (NRC, 1996).

Body Energy Reserves

Maintenance can be impacted by body condition score (BCS) in mature beef cows. In Hereford \times Charolais cows, an inverse relationship existed between BCS and energy requirements (Klosterman et al., 1968). Work by Thompson et al. (1983) indicated that in Angus \times Hereford cows, three-fourths of the variation in energy retention was explained by regressing retained energy on metabolic body weight. The same technique with beef \times dairy cows revealed only one-third of the variation suggesting both the total amount of body fat stores and the location of those storage sites influences maintenance energy requirements. Maintenance may be altered by increased body insulation from subcutaneous fat stores in beef cattle, as opposed to internal fat stores typical with dairy cattle (Callow, 1961; Charles and Johnson, 1976).

Grazing Activity, Environmental Conditions

As described by the NRC (1996), data are limited pertaining to the efficiency of ME use for movement. One could argue whether activity and movement is maintenance or a productive function. Regardless, it cannot be argued that grazing cattle routinely walk substantially farther than penned cattle. Grazing cattle, therefore, expend more energy, but the extent to which animals on pasture expend more energy for activities not exclusive to grazing (standing, changing positions, eating, ruminating) has not been well studied. The rate and extent to which grazing cattle expend energy is regulated individually and/or collectively by forage quality and quantity, weather, water distribution, and topography. When compared to penned cattle, the estimated increase in

maintenance energy requirements from grazing is 10 to 20% in favorable grazing conditions, and 50% for cattle on difficult terrain. Grazing cattle were estimated to have a 46% greater energy requirement compared with stall-fed cattle (Havstad and Malechek, 1982). Other researchers (Osuji, 1974) reported that grazing animals have 25 to 50% greater energy requirements than pen-fed animals. Those authors cited energy expenditures from walking, along with consuming forages of lower DM ultimately contribute to the elevated energy outflows by grazing animals.

In cattle, heat production and dissipation are controlled to maintain a constant body temperature. Heat production is generally disjoined from ambient air temperature and is regulated by feed intake, and body temperature is controlled through heat dissipation (NRC, 1996). When effective ambient air temperature increases above the upper critical temperature, feed intake is reduced. When body temperature becomes elevated, the consequence is greater metabolic rate by work from heat dissipation by tissues. As a result, maintenance requirements increase. Conversely, maintenance energy requirements increase when ambient air temperature decreases below the lower critical temperature because metabolism must increase to generate heat for body temperature maintenance. Animals have the fundamental ability to acclimate or adapt (either behaviorally or physiologically) in response to changes in environmental constraints to minimize negative effects of adverse conditions. The maintenance requirement of cattle changes by $0.0007 \text{ Mcal per BW}^{0.75}$ for every degree that ambient temperature varies from 20° C (NRC, 1996). Situations of cold stress or heat stress increase maintenance requirements further, and are influenced by multiple factors including topography or physical surroundings, animal behavior, diet, and genetics.

Intake Regulation of Beef Cattle and Limit-Feeding

Mechanisms that control feed intake in beef cattle are multifaceted and not well understood (NRC, 1996). Satiety is ultimately regulated by control centers in the brain which are stimulated by various anorexic and orexic inputs (Grovm, 1988). On a physical level, the broadly accepted concept of intake regulation is that intake of fibrous, low-energy feedstuffs is controlled by physical aspects including rumen fill and passage rate, while ingestion of high-energy, high-concentrate feeds is dictated by other metabolic processes. This theory was challenged by Ketelaars and Tolkamp (1992) who reported a linear relationship between OMI and OMD for OMD between 30 and 84%. The authors argued that if energy demand controlled intake of highly-digestible feedstuffs, then OMI would eventually plateau as OMD increases. Additionally, intake increased during lactation and decreased with pregnancy (Ketelaars and Tolkamp, 1992a) leading Tolkamp and Ketelaars (1992) to conclude that ruminants consume an optimal amount of feed necessary for production as opposed to simply consuming as much as possible. Regardless, numerous dietary, physiological, environmental, and management conditions impact feed intake. Nutritional influences on feed intake have been widely evaluated and perhaps have the greatest effect on feed intake, thus a review of regulation of intake by forage- and concentrate-fed cattle is warranted.

Forage and Dietary Factors Affecting Feed Intake in Forage-Fed Cattle

The chemical composition of forages is highly variable within and across plant species (Bohnert et al., 2011). Nutrient concentrations are influenced by plant variety, growing conditions, and management. Blaser et al. (1964) noted that plant physiological and morphological development has the greatest impact on nutrient composition. Blaser

et al. (1964) reported a decreasing plant leaf/stem ratio is indicative of advancement in maturity. Nitrogenous compounds comprise less of the DM as plants mature, and such changes in nutrient composition are concurrent with increases in structural carbohydrates contributing to the fibrous constituents of forages (Van Soest, 1965). It has been long recognized that plant maturity impacts the fiber component of forages, and through its negative association with digestibility and passage rate, effects intake (Peterson et al., 1974).

Cline et al. (2010) examined the influence of seasonal advancement and grazing treatment (season-long or twice-over rotation) on dietary composition, intake, site of digestion, and microbial efficiency in beef steers grazing native range. In a two-year study, ruminally and duodenally cannulated steers sampled pastures from early June to mid-November. Diet in vitro organic matter disappearance (IVOMD) declined in both years and both grazing treatments with progressing season. Intuitively, dietary N decreased concurrent with an increase in fiber across both years. Interestingly, OM intake (g/kg of BW) was not impacted by grazing treatment or seasonal advancement. Total tract and apparent ruminal OM digestion decreased with advancing season and were similar between treatments. However, microbial efficiency (g of microbial N/kg of OM truly fermented) was elevated for season-long compared to the twice-over rotation treatment (15.1 vs. 10.8 ± 1.6 g, respectively). The investigators concluded forage quality and intake decline with progressing season. Although rate of passage was not measured, it is likely the depression in digestibility was related to retention time thereby impacting rumen volume and forage intake.

The rate and extent of forage digestion is a function of protein and energy availability to the rumen microbial population (Mertens and Ely, 1982). As plant maturity advances, fiber components increase concurrent with reductions in soluble component concentrations (Merchen, 1988). Consequently, N supplied to rumen microbes is limited for cattle consuming low-quality forages. Therefore, reductions in digestibility, rate of passage, and ultimately DMI are often attributed to diet protein deficiencies (Kunkle et al., 2000). Accordingly, previous reports have consistently documented the improvement in forage intake (McCollum and Galyean, 1985; Petersen et al., 1985) and performance (Beaty et al., 1994; Schauer et al., 2005) from protein supplementation to cattle consuming low-quality forages.

Adams et al. (1996) and Köster et al. (1996) reported DIP as first limiting to the utilization of poor-quality forages. The latter authors conducted a metabolism experiment evaluating the effect of increasing DIP levels on forage intake and digestion in beef cows. Cows were given ad libitum access to low-quality (1.9% CP, 77% neutral detergent fiber (NDF)) native tallgrass-hay. Supplemental DIP (sodium caseinate, 90% CP) levels ranged from 0 to 720 g/d in 180 g intervals. Significant quadratic increases in forage OM intake up to 540 g/d were reported. Total volatile fatty acid (VFA) and ammonia concentrations increased in response to supplemental DIP. Microbial N flow and efficiency increased linearly with increasing DIP levels. It was concluded supplemental DIP enhances rumen fermentation thereby directly impacting rate of passage and stimulating forage intake. Further, the investigators calculated the DIP requirement of nonpregnant, mature cows to be 11.1% of digestible OM.

Similar results were observed in a study conducted by Del Curto et al. (1990). Steers grazed dormant tallgrass-prairie forage and were fed one of three supplements at 0.50% BW (DM). Containing varying proportions of soybean meal and sorghum grain, supplements were formulated to contain 13.5, 24.5, and 39.6% CP DM supplying 40, 79, or 120% of animal requirements, respectively. Quadratic responses to protein supplementation were reported for forage and total OM intake. There was a tendency for total tract OM digestibility to respond in a comparable fashion to protein supplementation. Total VFA tended to increase as protein level increased.

Forage proteins are promptly degraded in the rumen (Klopfenstein et al., 2001). This observation renders them excellent and poor sources of DIP and UIP, respectively. Blasi et al. (1991) found an increase in cow milk production and calf gain in response to UIP supplementation (0.23 kg/hd/d). This suggests MP may be limiting for cattle consuming forage-based diets; particularly those with increased requirements such as early-lactation females or rapidly growing calves. However, cow forage intake across treatments was similar. Sletmoen-Olson et al. (2000) evaluated effects of UIP on forage utilization and performance of beef cows during late-gestation and early-lactation. Undegraded intake protein, supplied through corn gluten meal and blood meal, was fed at three levels (53, 223, or 412 g UIP/kg supplement DM). No response to UIP supplementation was observed for forage OM intake during gestation. Independent of treatment, forage OM intake quadratically decreased and increased during gestation and early-lactation, respectively. Interestingly, non-supplemented cows had greater forage intakes than supplemented counterparts postpartum. These data suggest supplemental UIP minimally impacts forage utilization provided DIP is adequate in the diet.

Collectively, results suggest forage DMI is influenced to a greater degree by DIP rather than UIP. Sufficient rumen microbial function requires adequate DIP. Through mechanisms controlling digestibility and passage rate, DIP appears to govern forage consumption.

Dietary Factors Affecting Feed Intake in Concentrate-Fed Cattle

While rumen and gastrointestinal fill limits intake by forage-fed cattle, once an adequate energy concentration is obtained, physiological factors become the principal governor of feed intake (NRC, 1996). In most production systems, cattle consume forages prior to entering the feedlot, and must be transitioned from forage to concentrate-based diets upon arrival (Stock, 2000). This adaptation period is vitally important because not only is the rumen microbiome acclimating to different substrates (Stock, 2000), but the animal itself is changing intake control mechanisms from gastrointestinal fill to energy consumption. Cattle appear to be particularly prone during this period to metabolic disorders, namely subacute acidosis (Stock, 2000; Brown et al., 2006). Stock (2000) further reported that nearly all cattle experience some extent of subacute acidosis, and it is an essential process for adaptation to concentrate diets. Many aspects of feedlot cattle nutrition and management can affect subacute acidosis including grain processing, type and amount of grain, inclusion of feed additives, and feed bunk management techniques (Milton, 2000). The most common and critical response by cattle experiencing subacute acidosis is reduced intake and/or erratic feed intake patterns (Milton, 2000). Feed intake dictates the amount of energy consumed in excess of maintenance, influencing ADG and G:F (Galyean and Defoor, 2003). Because intake, acidosis, and forage inclusion level in concentrate diets are intricately related, this

discussion will center on those associations as it pertains to intake regulation of concentrate-fed cattle.

Milton (2000) noted that forages have historically been included in finishing diets to minimize acidosis challenges and acclimate cattle to high-grain diets. Previous survey data indicate that finishing diets generally contain between 4.5 to 13.5% (DM basis) forage (Galyean and Gleghorn, 2001). Similar values were more recently reported by Vasconcelos and Galyean (2007). As noted by Galyean and Hubbert (2014) the addition of a fibrous, bulky feed that is high in NDF to a fibrous diet will reduce DMI. Likewise, DMI will increase when a fibrous feedstuff is added to a high-concentrate diet because the animal is attempting to maintain constant energy intake as energy in the diet has been diluted. Logically, increasing DMI to compensate for energy dilution is possible until forage level is high enough to restrict intake (Galyean and Defoor, 2003). Alfalfa included in finishing diets at 10 and 20% (DM basis) produced similar ADG, but ADG was reduced when alfalfa was fed at 30% of the diet (Bartle et al., 1994). Other data suggest minor changes in fiber inclusion in the diet due to either increasing forage level or feeding a different source of fiber will increase DMI (Galyean and Defoor, 2003). Gains were greater when finishing cattle were fed either 7.5 or 10% (DM basis) sorghum sudangrass than 10% alfalfa hay (Guthrie et al., 1996). Galyean and Defoor (2003) concluded that DMI of high-concentrate diets would be influenced by energy dilution only if differences in forage level are large, while changes in DMI due to minor changes in fiber level, may be a consequence of factors other than energy dilution (i.e. rumen pH, digesta kinetics).

While multiple factors may contribute to influence DMI, it is likely that consumption is most fundamentally related to metabolic conditions, namely acidosis. Forage NDF and chewing time was positively associated in work by Armentano and Pereira (1997), implying added forage enhances saliva production. Rumen pH is a function of VFA production and absorption and the addition of buffers from saliva (Allen, 1997). Galyean and Hubbert (2014) indicated that increasing forage or NDF intake raises rumen pH. Apart from the compensation of energy dilution, increases in roughage level which increase salivary production appear to stimulate intake by concentrate-fed cattle (Galyean and Defoor, 2003). Alterations in rumen VFA production associated with inclusion of forage in concentrate diets may also partially account for the influence of forage on DMI (Galyean and Hubbert, 2014). Propionate infusion decreased feed intake (Allen et al., 2005), suggesting reduced propionate production from greater dietary forage inclusion may increase DMI.

Limit-Feeding

Limit-feeding references the concept of restricting intake to less than ad libitum based upon anticipated or known eating behavior (Galyean, 1999). Galyean (1999) noted several additional feed intake management techniques can be associated within limit-feeding including limited maximum intake, plateau feeding, percentage restrictions, feed additives which inhibit feed intake, and time restriction. Bunk management systems such as “clean” or “slick” bunk programs, in which intake is regulated such that no feed is remaining for a specific time interval prior to the next feeding, is essentially a form of time restriction (Pritchard and Bruns, 2003). Limit-feeding can be contrasted with programmed-feeding, in which net energy equations are used to determine the amount of

feed necessary for maintenance and a precise rate of gain (Galyean, 1999). Regulating feed intake has historically been used in various management situations and may be advantageous when feeding beef cattle. Multiple reasons for the use of limit or programmed-feeding have been proposed (Owens et al., 1995): 1) as an alternative to traditional pasture or forage-based systems; 2) as a means of avoiding over-consumption or intake variation; 3) as a method of simplifying bunk management; 4) as a technique for reducing manure excretion; 5) as a means of identifying ill cattle; 6) as method of facilitating transition to ad libitum consumption of a finishing diet; 7) as a technique for improving feed efficiency. Perhaps additional benefits of limit-feeding, specific to beef cows, are to prevent feed wastage and over conditioning.

National research council (NRC, 1996) net energy equations imply feed efficiency should improve as intake increases beyond maintenance levels, because energy consumed in excess of maintenance is converted to gain or other productive functions (i.e., lactation, reproduction). However, improvements in feed efficiency by limit-feeding or restricting intake of growing and finishing cattle are well documented in the literature (Prawl et al., 1997; Galyean, 1999). Gunter et al. (1996) fed diets containing 60, 75, or 90% concentrate to growing steers programmed-fed to gain 1 kg/d. The authors reported that while concentrate level had little impact on performance, F:G was improved by limit-feeding as compared to allowing cattle ad libitum access to feed. Hicks et al. (1990) observed improvements in F:G by 8.4 to 11% when yearling steers and heifers were restricted to 85 and 89%, respectively, of ad libitum intake of a finishing diet. Feed efficiency of steers was not influenced by offering all-concentrate diets either for ad libitum access or restricting to 90 and 80% of ad libitum intake (Murphy and

Loerch, 1994). Feed conversion was improved for growing cattle fed a high-moisture corn diet at 70% of ad libitum consumption as opposed to feeding a corn silage diet ad libitum or a corn silage and high-moisture corn diet at 80% of ad libitum intake (Loerch, 1990). Feed efficiency was improved 0.6% for each 1% of moderate feed restriction (\leq 15% of ad libitum intake) (Sainz, 1995). Loerch and Fluharty (1998) and Galyean (1999) noted that while restricted intake or programmed feeding of high-energy diets to growing cattle is readily practiced, the adoption of such methods for finishing cattle has been uncommon. Hindered ADG, lower carcass weight, increased feeding period length and decreased marbling are potential risks with both growing and finishing cattle if DMI is restricted to the extent that energy or protein intake is inadequate.

Limit-feeding nutrient-dense diets have been proven efficacious to meet the requirements of beef cows. Trials conducted by Loerch (1996) and Schoonmaker et al. (2003) demonstrated that corn-based diets during gestation and early-lactation did not influence cow or calf performance compared to offering ad libitum access to hay. Angus \times Simmental cows and calves limit-fed (10.6 kg DM per pair per d) either a whole corn or cracked corn diet from parturition to breeding had similar cow BW, BCS change and calf ADG to those receiving ad libitum access (16.1 kg DM per pair per d) to hay (Tjardes et al., 1998). In a study comparing either corn gluten feed (CGF) or DDGS with alfalfa hay in limit-fed diets (10.1 kg DM per pair per d) for postpartum cows, final cow BW and BCS were similar, although milk production and calf gain were greater for pairs fed CGF (Shike et al., 2009). The same authors conducted a similar trial using cornstalks in the diet, and ending cow BW and calf ADG were not different between treatments. Neither A.I. conception nor overall pregnancy rates were influenced by treatment in

either study. Warner et al. (2011) compared diets comprised of WDGS or CCDS and cornstalks to a forage diet (bromegrass hay, cornstalks, alfalfa haylage) offered ad libitum. The limit-fed WDGS diet (7.7 kg DM per cow per d) tended to produce greater ADG than the forage diet (10.4 kg DM per cow per d) when fed to nonlactating, nongestating beef cows. Replacing whole corn and soybean meal with WDGS or CCDS in corn silage-based limit-fed diets did not affect cow BW, BCS, 205-d adjusted calf weaning BW, or pregnancy % (Faulkner et al., 2013).

While restricted- or programmed-feeding methods appear to generally improve G:F of growing and finishing cattle and enable maintenance of BW and BCS in reproducing females (provided requirements are met), the physiological mechanisms responsible for such improvements are not well understood but thought to be related to changes in diet digestibility (Galyean, 1999). Early research with dairy cows indicated that the energy value of the diet decreased as intake increased (Moe et al., 1965). Colucci et al. (1982) reported a positive correlation (0.81) between energy digestibility and total tract retention time, and that increased retention time was associated with lower DMI. Total tract DM and OM digestibility of corn-based diets fed to crossbred steers decreased as intake level increased from 1 to 2 times maintenance intake (Galyean et al., 1979). In agreement, Edionwe and Owen (1989) concluded that depressions in digestibility may be related to increased DMI. Steers restricted to 80% of ad libitum DMI had improved diet digestibility compared to those offered ad libitum access to feed in work done by Clark et al. (2007).

The Interaction Between Nutrition and Reproduction in Beef Cows

In a review of nutritional controls of beef cow reproduction, Hess et al. (2005) commented that scientists and livestock producers alike have long understood the importance of adequate nutrition for reproductive success. The relationship between nutrition and beef cattle reproduction is complex and has been investigated lengthily in reviews by Randel (1990) and Short et al. (1990). Understanding how reproduction is manipulated by nutrition is essential, because reproduction is a function of low biological priority (Dunn and Moss, 1992). Given the subject of this dissertation, a discussion is needed regarding beef cow reproduction as it is influenced by nutrition, with particular emphasis on pre-partum and post-partum stages of production. Hess et al. (2005) noted that because nutrition can be regulated by cattle producers, the influence it has on reproduction will likely remain a critical area of research by the academic community.

Pre-Partum Nutrition

Some of the earliest research establishing the fundamentals between diet energy level pre-partum and reproduction was conducted by Wiltbank et al. (1962). Hereford cows fed recommended levels of energy both pre-partum and post-partum had conception rates of 95%. While similar pregnancy rates were observed for cows fed recommended levels of energy post-calving but restricted to 50% of required energy intake pre-calving, the interval from calving to first estrus was 17 d longer. Corah et al. (1975) reported that pre-partum nutrition level did not affect the interval from calving to first estrus in either primiparous heifers or mature cows. In that study, adequate BCS at the start of the pre-partum feeding period was attributed to the lack of response to energy level. Research by Richards et al. (1986) demonstrated that BCS at parturition had the greatest impact on the resumption of estrus and subsequent pregnancy rates, because increased levels of

nutrition post-calving did not influence the proportion of females displaying estrus or pregnant if BCS at calving was adequate (≥ 5.0). Pre-partum supplementation of spring-calving cows (BCS ≥ 5.0) grazing upland native Sandhills range did not influence pregnancy rates, the interval from calving to conception or the percentage of females conceiving during the first cycle of the breeding season (Stalker et al., 2006). However, Brahman-influenced cows in low BCS (4.3) had lower pregnancy rates than cows in a BCS 6.1 (Flores et al., 2007), confirming the importance of BCS at parturition on subsequent reproductive performance in beef females.

In an attempt to further define the specific biological mechanisms responsible for the improvement in reproduction observed with increased pre-partum nutritional level, Lents et al. (2008) studied the effects of BCS at calving on follicular and estrus characteristics of mature cows. Cows managed to calve in thin BCS (< 5.0) had a longer post-partum interval (PPI) than those fed to be in a moderate BCS (≥ 5.0). While estrus behavior was not different, size of the dominant follicle and pregnancy rates were greater for moderately-conditioned cows as opposed to thin cows, and the authors concluded moderate BCS at calving is essential for decreasing PPI and increasing the probability of conception. In agreement, Whitman (1975) noted that as BCS at calving increased, the odds of resuming estrus by 60 to 90 d post-calving improved. Reduced BCS was associated with decreased secretion of luteinizing hormone (LH), reduced ovarian and corpora lutea weights and the failure of initiation of estrous cycles (Rasby et al., 1991). Mature Angus-cross cows in moderate (5.1 to 5.6) BCS prior to calving achieved first-service timed-A.I. conception rates of 50-58% and overall pregnancy rates of 88-92% (Radunz et al., 2010). Consistent with other data, Momont and Pruitt (1998)

recommended that mature cows obtain a BCS of 5.0 prior to calving to enable females to conceive during a defined breeding season.

Supplementing first-calf heifers to maintain a BCS of 6.0 or greater at calving was suggested by Anderson and Lewis (1991). Whittier et al. (2005) noted this recommendation has been founded on the principle that young females have a requirement for growth and require additional body energy reserves to compensate for lactation demands. Mulliniks et al. (2012) completed a retrospective evaluation of BCS at calving with pregnancy rate and d to first postpartum ovulation in young cows (2-3 yr of age) in New Mexico. Interestingly, d to first postpartum ovulation was not different, nor were pregnancy rates different between cows calving in BCS 4, 5, or 6. The authors concluded that BCS at calving was a poor indicator of reproduction in cows adapted to extensively grazing semiarid rangeland. This is one of few studies that contradicts the large volume of research indicating that pre-partum nutrition (as indicated by BCS) is most critical for determining the length of the PPI and pregnancy rate (Hess et al., 2005).

Post-Partum Nutrition

The duration between parturition and breeding represents a period of increased nutrient demand by the beef female due to lactation. Nutritional programs must be evaluated, and altered if needed, during this stage of the production cycle to ensure requirements are being met. While previous data (Richards et al., 1986; Lents et al., 2000) suggest that body energy reserve at calving is the most critical factor affecting PPI and subsequent pregnancy rate, both pre- and post-calving nutrient intake interact with BCS to affect subsequent reproduction in lactating females. Decreased BCS at calving increases PPI, and nutrient intake post-partum can alter the length of the PPI in females

with low BCS (Wettemann et al., 2003). However, ovulation occurs later for cows in low BCS, even if they gain substantial BW and BCS following parturition, than for cows calving in adequate BCS.

Randel (1990) noted that while insufficient energy intake during late-gestation hinders reproduction even if energy consumption is adequate post-partum, pregnancy rates will be diminished further if energy intake is deficient upon calving. A review by Randel (1990) indicated that pregnancy rates of females consuming diets deficient in energy post-partum achieved pregnancy rates from 50 to 76%, far below that of females consuming diets adequate in energy (87 to 95%). It was concluded that dietary energy is related to reproduction in lactating beef cows and heifers, and that energy consumption interacts with BCS at parturition to influence subsequent reproduction. The effects of BCS at calving (4 to 6) and rate of BW gain post-partum until breeding (0.45 or 0.90 kg/d) were studied in primiparous cows (Spitzer et al., 1995). Regardless of BCS at calving, the authors reported improved pregnancy rates (70 vs. 84%) and calf weaning BW (188 vs. 197 kg) for cows on an increased plane of nutrition. Ciccioli et al. (2003) fed first-calf females, calving in a BCS of 4.5 to 5.0, to gain either 0.45 or 0.90 kg/d during the post-partum phase. Cows fed a higher level of nutrition had a reduced PPI by approximately one full cycle, and attained an increase in pregnancy rate at the first estrus by 18 percentage units. Increased ME intake post-partum resulted in a linear decline in PPI (Lalman et al., 1997). These data demonstrate the importance of increasing the energy status of post-partum cows in minimizing BW and BCS losses, improving pregnancy rates, and shortening the PPI.

Aside from energy, conception rates of lactating cows and heifers appear to be influenced by both pre-calving and post-calving protein intake (Randel, 1990). When compared to females consuming adequate amounts of protein, cows and heifers receiving protein-deficient diets during gestation had decreased pregnancy rates. After reviewing eight trials, the same observation was reported for lactating females deficient in protein during the post-partum period (Randel, 1990). In cows receiving isocaloric diets, deficient protein intake during both gestation and lactation decreased pregnancy % by 42 percentage units (Sasser et al., 1988). These results indicate that protein, along with energy, influences reproduction in both pre-partum and post-partum beef females.

Collectively, the literature strongly suggests that BCS at calving and nutrient intake are the principal governors of reproduction in beef females. The influence of specific nutrients (energy, RDP, RUP, minerals, and vitamins), either individually or in combination with each other, on reproductive performance is beyond the scope of this review. Furthermore, hormone production, metabolites, and body energy reserves interact to influence the development of follicles, estrus, and ovulation in beef females. While reproduction is a complex phenomenon, nutrition plays the most integral role in its success or failure.

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Feed Efficiency of Early Weaning

**The effect of calf age at weaning on cow and calf performance and feed utilization
by cow-calf pairs¹**

J. M. Warner,* K. H. Jenkins,† PAS, R. J. Rasby,* PAS, M. K. Luebke,† PAS, G. E.

Erickson,* PAS, and T. J. Klopfenstein*²

*Department of Animal Science, University of Nebraska-Lincoln, Lincoln 68583

†University of Nebraska, Panhandle Research and Extension Center, Scottsbluff 69361

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² To whom correspondence should be addressed: tklopfenstein1@unl.edu, (402) 472 - 6443

ABSTRACT

The effect of calf weaning age on cow and calf performance and feed utilization was investigated over 2 yr. Multiparous, crossbred, lactating beef cows ($n = 156$) with summer-born calves were blocked by prebreeding BW, stratified by calf age, and assigned randomly to 1 of 4 treatments within strata. The experiment was a randomized complete block design with a 2×2 factorial arrangement of treatments with three replications (pens) per treatment per year (total $n = 24$). Factors were: 1) location; Agricultural Research and Development Center (**ARDC**) or Panhandle Research and Extension Center (**PHREC**) and 2) calf weaning age; early-weaned (**EW**) at 91 ± 18 d of age or conventionally weaned (**CW**) at 203 ± 16 d of age. All cows and calves were fed a common diet from early to conventional weaning time within each yr and location. Cows with weaned calves were limit-fed (6.9 kg DM/cow daily) while EW calves were offered *ad libitum* access to feed (4.0 kg DM/calf daily). Nursing pairs were fed an equivalent amount of DM (10.8 kg/pair daily). Initial cow BW and BCS were similar ($P \geq 0.26$), but BW change from early to conventional weaning was 17 kg greater ($P \leq 0.01$) for EW cows. Cow BCS and conception rates were not impacted ($P \geq 0.38$) by weaning. Calf BW at conventional weaning was greater for CW than EW at ARDC, but greater for EW than CW calves at PHREC. Calf ADG per unit of total feed energy intake was greater for nursing pairs at ARDC, but not different between EW and CW at PHREC indicating early-weaning may have minimal effect on reducing feed energy requirements.

Key Words: cow-calf pairs, efficiency, feed utilization, weaning

INTRODUCTION

In beef cow-calf production systems, weaning most often occurs when calves reach a conventional age of 6 to 8 mo, independent of season of birth (Pate et al., 1985; Thrift and Thrift, 2004). Situations such as reduced forage availability, decreased milk production by the dam, or low cow BCS may arise in which early calf weaning is a viable management strategy. The benefits of sparing available forage (Arthington and Minton, 2004; Meyer et al., 2012), enhancing reproduction (Houghton et al., 1990) and reducing cow maintenance energy requirements (NRC, 1996) by early-weaning are well documented. Given that early-weaned calves are inherently efficient at converting feed to gain (Myers et al., 1999b); early-weaning is often regarded as a more feed efficient management practice by reducing the total feed energy required by a cow-calf pair (Peterson et al., 1987). Peterson et al. (1987) measured this efficiency by feeding different diets to pairs and weaned calves and calculated energy intakes with assumed feedstuff energy values. An alternative approach that would minimize variation in diet energy content would be to feed a common diet to all cows and calves at a similar DMI. Our objectives were to evaluate the impact of calf age at weaning on: 1) cow-calf performance and reproduction and 2) the feed utilization by the cow-calf pair of developing a weaned calf to 205 d of age when pair-fed a common diet.

MATERIALS AND METHODS

All procedures and facilities described in the following experiment were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee. Multiparous (4.6 ± 1 yr of age), crossbred (Red Angus \times Red Poll \times Tarentaise \times South Devon \times Devon), lactating beef cows (total $n = 156$) with summer-born calves were

utilized in a 2 yr experiment conducted at both the University of Nebraska-Lincoln Agricultural Research and Development Center (**ARDC**) feedlot located near Mead, NE (41° 13' N, 96° 29' W; elevation 369 m) and the Panhandle Research and Extension Center (**PHREC**) feedlot at Scottsbluff, NE (41° 51' N, 103° 40' W; elevation 1,186 m). Historical mean annual precipitation has been approximately 72 and 34 cm at ARDC and PHREC, respectively. The trial was a randomized complete block design with a 2 × 2 factorial arrangement of treatments. Each yr, cows within each location (n = 37 and 41 cows at ARDC and PHREC, respectively [yr 1]; n = 40 and 38 cows at ARDC and PHREC, respectively [yr 2]) were blocked by pre-breeding BW (heavy, medium, & light), stratified by calf age, and assigned randomly within strata to one of two calf weaning treatments with three replications (pens) per treatment per yr per location (total n = 24 pens; 5 - 7 pairs per pen). Location was considered part of the treatment design given the difference in climate, therefore treatment factors included: 1) calf age at weaning; early-weaned (**EW**) at an average age of 91 ± 18 d or conventional-weaned (**CW**) at an average age of 203 ± 16 d and 2) research location; eastern (ARDC) or western (PHREC) Nebraska. Cows remaining in the herd for two consecutive yr were assigned to the same treatments each yr. Cows removed upon completion of yr 1 of the experiment were replaced with pregnant, multiparous (4 yr of age) females of similar genetic composition and calving date from a commercial ranch in southwest Nebraska. Reasons for cow removal from the experiment between the completion of yr 1 and the beginning of yr 2 included: failure to become pregnant (n = 10), calf death during the calving season (n = 4), undesirable teat or udder conformation (n = 2), poor disposition (n = 1), and death (n = 1).

Prior to the beginning of the experiment each yr, cows within locations were managed as a common group while calving in June and July in earthen feedlot pens without access to shade. Cows were vaccinated approximately one mo prior to calving against *bovine rotavirus*, *bovine coronavirus*, *escherichia coli*, and *clostridium perfringens type C* (ScourGuard® 4KC, Zoetis, Florham Park, NJ). Post-calving, cows were limit-fed (9.1 kg DM/cow daily) high energy diets (Table 1) to meet nutrient requirements for early-lactation. Within 24 h of parturition, calving date, calf birth weight, and sex were recorded, male progeny were band castrated, and all calves were vaccinated against *clostridium chauvoei*, *septicum*, *novyi*, *sordellii*, *perfringens types C&D*, and *haemophilus somnus* (Vision® 7 Somnus, Merck Animal Health, Summit, NJ). All calves received a second vaccination of Vision® 7 Somnus and were vaccinated against *infectious bovine rhinotracheitis*, *bovine viral diarrhea (types 1 & 2)*, *parainfluenza 3*, and *bovine respiratory syncytial virus* (Bovi-Shield Gold® 5, Zoetis, Florham Park, NJ) concurrent with the time of early-weaning. Upon trial initiation approximately October 6 (September 27 and 25 at ARDC and PHREC, respectively [yr 1]; October 15 and 18 at ARDC and PHREC, respectively [yr 2]), cow-calf pairs assigned to the EW treatment were separated at an average calf age of 91 d, after which cows and calves were managed and fed independently for the duration of the trial. Cows and calves assigned to the CW treatment remained together throughout the trial and these calves were weaned approximately January 28 (January 22 and 24 at ARDC and PHREC, respectively [yr 1]; February 3 at both ARDC and PHREC [yr 2]) at an average calf age of 203 d. Cow BCS (Wagner et al., 1988; 1 = emaciated; 9 = obese) was assessed visually by the same experienced technician across locations at trial initiation and

completion. Two-day consecutive cow and calf BW measurements (Stock et al., 1983) were recorded to determine cow weight change and calf gain from October to January. Prior to collecting weights at the beginning of the trial, all pairs were limit-fed (9.1 kg DM/pair daily) a diet (Table 1) for 5 d to minimize variation in gastrointestinal tract fill (Watson et al., 2013). At trial completion, both CW (following separation from their dams) and EW calves were limit-fed (approximately $4.5 \text{ kg} \cdot \text{calf}^{-1} \cdot \text{day}^{-1}$; DM basis) the same diet for 5 d before taking weights. All cows were limit-fed 6.8 kg DM (Table 1) for 5 d prior to weighing.

From October through January, EW cows within each location were limit-fed 6.8 (yr 1) or 7.0 (yr 2) kg DM/cow daily a diet designed to meet maintenance energy requirements for a nonlactating cow in mid-gestation (Table 1). Concurrently, the EW calves within each location were offered *ad libitum* access to the same diet as the cows. Feed refusals (if present) by the calves were collected, sampled, and DM determination was conducted using a 60°C forced air oven for 48 h to calculate DMI. The CW cow-calf pairs that remained together were then limit-fed the equivalent amount of DM consumed in total by the EW cows and calves, accomplished by summing the intakes of the two groups. Intakes for the CW cow-calf pairs were adjusted once weekly based on the average consumption of the EW calves from the prior wk. No attempt was made to measure intake between the CW cow and her calf. Consequently, the total DMI between either the separated EW cows and calves or the CW pairs together was intended to be equal by design and increased throughout the experiment due to growth and diet consumption by the EW calf. The ratio of calf BW gain to the total feed energy intake by the cow-calf pair was subsequently calculated as a measurement of the feed efficiency of

early weaning. All cattle were maintained in earthen feedlot pens and received their diets as a TMR once daily in concrete fence-line feed bunks with the following bunk space allotments: 0.6 m per EW cow, 0.3 m per EW calf, and 0.9 m per CW cow-calf pair.

Cows were exposed to Simmental \times Angus bulls at a bull:cow ratio of 1:10 for 60 d beginning approximately September 26 each year, and breeding occurred in the pens. Cows were vaccinated approximately 1 mo prior to the start of the breeding season against *infectious bovine rhinotracheitis*, *bovine viral diarrhea (types 1 & 2)*, *parainfluenza 3*, *bovine respiratory syncytial virus*, and *leptospirosis* (Bovi-Shield Gold[®] FP[®] 5 VL5 HB, Zoetis, Florham Park, NJ). All bulls passed a breeding soundness examination administered by a licensed veterinarian. Pregnancy was diagnosed via transrectal ultrasonography 60 d after bull removal.

All data were analyzed as a randomized complete block design using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) with pen as the experimental unit. Model fixed effects included calf age at weaning, location, and the weaning \times location interaction. Because the proportion of steer and heifer calves was unequal among treatments, calf sex was initially included as a covariate for all variables tested and was subsequently removed if not significant. Block and year were included in all analyses as random effects, and significance was declared at $P \leq 0.05$.

RESULTS AND DISCUSSION

Early-weaned calves across both yr had a daily DMI of 4.1 (ARDC) and 3.9 (PHREC) kg per calf from October through January (Table 2). This amount was adjusted weekly, and added to the 6.9 kg/d DM fed to the EW cows to derive the total amount fed daily to the CW pairs. The combined total intake of the EW cows and calves was 11.0

and 10.9 kg DM/d for ARDC and PHREC, respectively. The CW pairs consumed 10.9 and 10.8 kg DM/d, for ARDC and PHREC locations, respectively. As a result, on average approximately 8.7 and 8.6 kg•pair⁻¹•day⁻¹ of TDN was supplied to both EW and CW treatments, respectively, regardless if pairs were separate or together. Unlike Peterson et al. (1987), the same diet was fed in the current study to all cows and calves regardless of weaning treatment within each year and location. This was done to eliminate potential variation in the energy value of the diet. A review of the literature indicates that this method to compare the feed efficiency between early- and conventional-weaned pairs has not been previously attempted.

In the current experiment, DMI of the EW calves was comparable to, but slightly lower than reported in previous studies for calves of similar BW and age. Myers et al. (1999b) weaned crossbred steers at 90 d of age (BW = 89 kg), and reported intakes of approximately 4.8 kg•steer⁻¹•d⁻¹ (DM basis) during the initial 125 d of the feeding period when fed a corn and corn gluten feed-based finishing diet. In another study by the same researchers (Myers et al., 1999c), calves (BW = 144 kg) ate 4.6 kg•steer⁻¹•d⁻¹ of a diet containing 77% dry corn (DM basis) from 127 to 208 d of age. Likewise, early-weaned Angus steers (100 d of age; BW = 123 kg) fed a whole-shelled corn finishing diet consumed 4.7 kg•steer⁻¹•d⁻¹ (DM basis) in the first 100 d in similar work by Barker-Neef et al. (2001). Previous research has focused on feeding grain-based finishing diets to young calves upon early-weaning in an effort to increase DMI, and thus energy intake. Published intake data are limited for calves of comparable BW and age when fed diets with high inclusion levels of distillers grains and crop residues as in our study. Our diets contained more forage (40%, DM basis) from either crop residue or corn silage than the

diets in the aforementioned studies. Ruminal fill may have slightly limited DMI, as young calves have less rumen capacity compared to older cattle (Lyford, 1988). The observed intakes were generally acceptable for cattle of this BW and age.

As intended, cow BW was not different ($P \geq 0.05$) among treatment means in October (Table 3), and there was no weaning age by location interaction ($P = 0.51$) for January cow BW. Cows located at PHREC had greater ($P < 0.01$) BW than ARDC cows, and EW cows had greater ($P = 0.02$) BW in January than cows that nursed their calves. The weaning age by location interaction was not significant for cow BW change, but EW cows gained more BW ($P < 0.01$) than their CW counterparts, and cows at PHREC outgained those at ARDC ($P < 0.01$). Our observation for cow BW change in response to early-weaning agrees with previous data. Angus \times Brahman cows gained 14 kg less BW compared to cows whose calves were weaned 60 d earlier (Pate et al., 1985). Early calf removal improved cow BW at the time of conventional-weaning in two additional studies using crossbred cows (Myers et al., 1999a, 1999b). Similarly, total BW gain was greater for mature cows and first-calf heifers when calves were weaned at 108 compared to 205 d of age (Schultz et al., 2005). This positive change in cow BW from early weaning is logical given calf removal diverts intake energy from lactation towards maintenance and gestation.

There was no weaning age by location interaction or weaning age effect for January cow BCS ($P = 0.60$) or BCS change ($P = 0.38$; Table 3). Interestingly, regardless of weaning treatment, cows at PHREC gained ($P < 0.01$) 0.4 BCS units while those at ARDC lost approximately 0.2 units between October and January. Why BCS did not respond in a similar manner as did BW is interesting. Calf removal has been

frequently reported to either enable females to gain BCS or minimize the extent of BCS losses (Myers et al., 1999a; Myers et al., 1999b; Arthington and Kalmbacher, 2003). Other researchers have also demonstrated that removing the energy need for lactation improves BCS (Schultz et al., 2005; Merrill et al., 2008). In most studies, early-weaned cows received *ad libitum* access to grazed pasture, such that forage quantity or quality was sufficient to support BCS improvements. In our study, cows were limit-fed to meet requirements, and BCS data indicate that energy intakes were adequate for maintenance. Considering that CW cows had similar ($P = 0.38$) BCS change to EW cows within a location, feed intake partitioned between the cow and calf appeared sufficient to meet lactation requirements. In general these changes in BW and BCS are numerically small and may have limited biological significance. Improvement in BW and BCS from early weaning beyond that observed in our study may likely be realized for cows with low BCS (Arthington and Minton, 2004), young cows (Lusby et al., 1981), and for cows given *ad libitum* access to feed.

There was no weaning age by location interaction ($P = 0.50$) for cow pregnancy rate nor were there effects of either location or calf weaning age (Table 3). The dates for early-weaning coincided with the start of the breeding season, and approximately two wk after the onset of breeding in yr 1 and 2, respectively. Previous (Lusby et al., 1981) and more recent data (Arthington and Kalmbacher, 2003; Arthington and Minton, 2004) indicate that early-weaning prior to the breeding season may increase cycling activity and conception rates in thin primiparous cows, and can reduce the duration of postpartum anestrus (Houghton et al., 1990). Two studies with mature cows (Myers et al., 1999a, 1999b) also reported that early-weaning improved pregnancy rates for cows with an

initial BCS of approximately 4.0. Pregnancy rates in this study suggest that mature cows in adequate BCS (≥ 5.0) prior to the onset of the breeding season may have limited reproductive response to early weaning when calves are weaned at approximately 90 d of age. This agrees with work by Story et al. (2000) in which early-weaning did not influence pregnancy rates when cows were at a BCS of at least 5.0 before calving.

The conception rates in the current experiment also add to a limited body of research demonstrating the reproductive performance of cows when limit-fed high energy diets throughout the entire breeding season. Several trials (Loerch, 1996; Tjardes et al., 1998; Schoonmaker et al., 2003; Shike et al., 2009) have found that limit-feeding high energy diets comprised of corn or ethanol co-products to cows in late-gestation or early-lactation does not hinder reproductive performance. In many of these trials the limit-feeding period ended at the start of the breeding season. Faulkner et al. (2012) limit-fed cows a diet of corn silage, whole corn, and soybean meal during a 55 d breeding season and reported conception rates (AI plus natural service) of 84 to 96%, supporting our data that cows managed throughout the breeding season, on a limit-feeding program which meets energy requirements, have acceptable breeding performance provided BCS at the beginning of breeding is adequate.

By design, calf BW was similar among treatments in October at the time of early-weaning (Table 4). Weaning age by location interactions were observed ($P < 0.01$) for both calf ADG and ending January BW. At PHREC, EW calves gained more resulting in greater ($P \leq 0.05$) January BW than CW calves. At ARDC, calves that nursed their dams had improved ($P \leq 0.05$) gain and ending BW over those weaned at 91 d of age. A weaning age by location interaction existed ($P < 0.01$) for calf BW per d of age at

conventional-weaning in January. Suckling calves had greater ($P \leq 0.05$) BW per d of age at ARDC, whereas EW and CW calves were not different at PHREC. Gains of early-weaned calves prior to a traditional weaning age appear to be strongly dependent on the diet fed. Several studies have reported that early-weaned calves have increased ADG and BW at a conventional-weaning time when fed grain-based finishing diets (Fluharty et al., 2000; Story et al., 2000; Barker-Neef et al., 2001). Likewise, early-weaned calves supplemented on pasture had similar gains and BW to those nursing cows (Arthington and Kalmbacher, 2003; Schultz et al., 2005). In our study, diets were formulated to provide adequate energy and protein intakes to allow the EW calf to gain BW at a rate comparable to that of the CW calves. Published data demonstrating the performance of early and conventional-weaned calves when fed the same diet are limited.

The ratio of calf BW gain to the total feed energy intake by the cow-calf pair may be an appropriate expression of the feed efficiency of early-weaning. It is a comparison of calf gain as a result of either direct diet consumption by the calf or the partitioning of feed between the cow and her calf plus the conversion of cow feed energy intake to milk production. Because diet energy levels were equal between weaning treatments, and DMI was measured for all animals, this relationship can be accurately described.

Consistent with calf BW and ADG, a weaning age by location interaction was observed ($P < 0.01$) for cow-calf pair G:F (Table 4). Total pair G:F was greater ($P \leq 0.05$) for CW than EW pairs at ARDC, while weaned and nursing pairs were not different at PHREC. In contrast, Peterson et al. (1987) reported that early-weaned pairs converted feed energy into calf ADG 43% more efficiently. The use of different diets among treatments, an inconsistent manner in which cows were fed (i.e. *ad libitum* vs. restricted intake), and the

lack of accounting for gastrointestinal fill when weighing may represent limitations with these data. Data from Moe et al. (1971) indicate that the efficiency of the conversion of ME towards lactation and maintenance in the cow is similar. In agreement, energy balance studies with primiparous cows (Freetly et al., 2006), reported that the efficiency of conversion of ME to lactation energy was 72%. The efficiency of transferring ME to tissue energy and then to lactation energy was 78%. This is verified from other previous data (Moe et al., 1971; Vermorel et al., 1982). If the efficiency of energy use for lactation or maintenance in the cow is similar, then the conversion of total feed energy intake to calf gain, between early and conventional weaning, is mainly a function of calf performance.

IMPLICATIONS

Weaning calves at 90 d of age appears to have marginal effect on cow BW and BCS change and pregnancy rates when cows are limit-fed high energy diets to meet requirements, provided BCS is acceptable (≥ 5.0) prior to the beginning of the breeding season. Because calf ADG per unit of feed energy intake for the cow and calf combined were relatively similar, the total energy requirements for weaned cows and calves or nursing pairs do not appear to be markedly different. Thus, decisions regarding early-weaning should be made on the discretion of management as opposed to feed efficiency.

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Table 1. Ingredient and nutrient composition of diets fed to all cows and calves from October to January by location and yr¹

Ingredient, %	Yr 1		Yr 2	
	ARDC ²	PHREC ³	ARDC ²	PHREC ³
Corn silage	--	--	40.0	40.0
MDGS ⁴	56.5	--	36.5	--
WDGS ⁵	--	58.0	--	38.0
Cornstalks	40.0	--	20.0	--
Wheat straw	--	40.0	--	20.0
Supplement ⁶	3.5	2.0	3.5	2.0
Calculated Composition				
DM, %	61.9	47.0	45.4	39.3
CP, %	19.0	18.8	16.1	15.3
TDN, %	80.0	80.0	78.0	78.4
NE _m , mcg/kg	1.94	1.94	1.87	1.90
NE _g , mcg/kg	1.52	1.52	1.46	1.48
NDF, %	47.3	54.9	47.1	51.1
ADF, %	25.2	21.6	25.3	22.0
Ca, %	0.75	0.77	0.58	0.81
P, %	0.50	0.49	0.44	0.41

¹All values presented on a DM basis.

²ARDC = Agricultural Research and Development Center.

³PHREC = Panhandle Research and Extension Center.

⁴MDGS = modified wet distillers grains plus solubles.

⁵WDGS = wet distillers grains plus solubles.

⁶Supplements contained limestone, trace minerals, vitamins and formulated to provide no greater than 200 mg/cow daily monensin sodium (Elanco Animal Health, Greenfield, IN).

Table 2. Daily DMI (kg \pm SD) by location and weaning treatment across yr

Item	ARDC ¹		PHREC ²	
	EW ³	CW ⁴	EW ³	CW ⁴
Cow	6.9 \pm 0.05	--	6.9 \pm 0.03	--
Calf	4.1 \pm 1.02	--	3.9 \pm 0.95	--
Cow-calf pair	--	10.9 \pm 1.13	--	10.8 \pm 1.00
Total	11.0	10.9	10.9	10.8

¹ARDC = Agricultural Research and Development Center.

²PHREC = Panhandle Research and Extension Center.

³EW = early-weaned at 91 d of age.

⁴CW = conventionally-weaned at 203 d of age.

Table 3. Performance of cows by location and weaning treatment

Item	ARDC ¹		PHREC ²		SEM	<i>P</i> -value		
	EW ³	CW ⁴	EW ³	CW ⁴		Wean ⁵	Loc ⁶	W × L ⁷
Cow BW, kg								
October	545	535	557	550	52	0.26	0.08	0.85
January	547	529	591	559	47	0.02	<0.01	0.51
Cow BW change, kg	2	-6	34	9	10	<0.01	<0.01	0.15
Cow BCS ⁸								
October	5.5	5.5	5.2	5.2	0.3	1.00	<0.01	0.59
January	5.4	5.3	5.6	5.6	0.4	0.60	0.03	0.60
Cow BCS change ⁸	-0.1	-0.2	0.4	0.4	0.2	0.38	<0.01	0.38
Pregnancy, %	89.9	85.4	92.5	95.2	6	0.88	0.25	0.50

¹ARDC = Agricultural Research and Development Center.²PHREC = Panhandle Research and Extension Center.³EW = early-weaned at 91 d of age.⁴CW = conventionally-weaned at 203 d of age.⁵Fixed effect of calf age at weaning.⁶Fixed effect of location.⁷Calf age at weaning × location interaction.⁸BCS on a 1 (emaciated) to 9 (obese) scale.

Table 4. Performance of calves by location and weaning treatment

Item	ARDC ¹		PHREC ²		SEM	P-value		
	EW ³	CW ⁴	EW ³	CW ⁴		Wean ⁵	Loc ⁶	W × L ⁷
Initial age ⁸ , d	91	91	91	89	--	--	--	--
Ending age ⁹ , d	205	205	206	202	--	--	--	--
Calf BW ¹⁰ , kg								
October	127	126	131	121	4	0.13	0.92	0.22
January	215 ^{b,c}	231 ^a	226 ^{a,b}	209 ^c	5	0.90	0.19	<0.01
Calf ADG, kg	0.78 ^{b,c}	0.93 ^a	0.84 ^b	0.77 ^c	0.1	0.09	0.02	<0.01
BW•d•age ¹¹ , kg	1.04 ^b	1.15 ^a	1.08 ^{a,b}	1.04 ^b	0.03	0.16	0.17	<0.01
Pair G:F ¹²	0.090 ^c	0.109 ^a	0.098 ^b	0.091 ^{b,c}	0.007	0.06	0.09	<0.01

¹ARDC = Agricultural Research and Development Center.²PHREC = Panhandle Research and Extension Center.³EW = early-weaned at 91 d of age.⁴CW = conventionally-weaned at 203 d of age.⁵Fixed effect of calf age at weaning.⁶Fixed effect of location.⁷Calf age at weaning × location interaction.⁸Age at the time of early-weaning across both yr.⁹Age at the time of conventional-weaning across both yr.¹⁰Actual weights.¹¹Weight per d of age at January conventional-weaning time.¹²Calf gain per kg of total pair feed TDN intake.^{a-c}Within a row, least squares means without common superscripts differ at $P \leq 0.05$.

Post-Weaning Management Systems

Effect of post-weaning management and age at weaning on growing and finishing performance, carcass characteristics, and economics of calves produced from an intensively managed cow-calf production system¹

J. M. Warner,* K. H. Jenkins,† PAS, R. J. Rasby,* PAS, G. E. Erickson,* PAS, and T. J.

Klopfenstein*²

*Department of Animal Science, University of Nebraska-Lincoln, Lincoln 68583

†University of Nebraska, Panhandle Research and Extension Center, Scottsbluff 69361

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² To whom correspondence should be addressed: tklopfenstein1@unl.edu, (402) 472 - 6443

ABSTRACT

Crossbred steers and heifers ($n = 152$, $BW = 231 \pm 34$ kg) sourced from 2 locations over 2 yr were utilized to evaluate post-weaning management and calf weaning age on growing and finishing performance, carcass characteristics, and economics. Cattle were sorted by weaning age, stratified by initial BW, and assigned randomly within strata to 1 of 2 post-weaning management treatments with 2 replications (pens, 7-12 animals per pen; based on location) per treatment per yr as a complete randomized design. The treatment design was a 2×2 factorial arrangement, treatment factors included: 1) calf age at weaning, early-weaned (**EW**) at 91 ± 18 d of age or conventionally-weaned (**CW**) at 203 ± 16 d of age; and 2) post-weaning management, fast-track (**FT**) or slow-track (**ST**). Fast-track cattle were grown (85 d) at an increased ADG before finishing (176 d). Slow-track cattle were grown (85 d) at a moderate ADG and grazed summer pasture (146 d) before finishing (163 d). Growing and finishing diets were common within yr. During the 85-d growing period, FT cattle had greater ($P < 0.01$) DMI (7.8 kg/calf daily) and ADG (1.41 kg) compared to ST. While initial finishing BW was similar ($P = 0.89$), DMI (12.1 kg/calf daily), ADG (1.84 kg), HCW (405 kg), and marbling were greater ($P \leq 0.03$) for ST compared to FT, likely due to age. Breakevens were similar ($P \geq 0.74$), but profitability greater ($P < 0.01$) for FT. Weaning age had minimal impact ($P \geq 0.05$), but post-weaning management influenced subsequent performance demonstrating the value of alternative management systems post weaning.

Key Words: beef cattle, management, post-weaning, system

INTRODUCTION

Early-weaning beef calves is a sound management practice in many situations including: limited forage quantity or quality, reduced milk production level, or decreased cow BCS. Although recent data (Warner et al., 2015) suggest that early-weaning does not improve total feed efficiency by the cow-calf pair, the early-weaned calf itself is efficient in converting feed to gain, and overall ADG through finishing was increased by early-weaning when calves were fed high-concentrate diets (Fluharty et al., 2000; Myers et al., 1999c). However, data regarding subsequent growing and finishing performance are limited for early-weaned calves when fed distillers grains and crop residue-based diets upon early-weaning and prior to entering the growing and finishing periods.

Adams et al. (2010) noted that both calf-fed and yearling post-weaning management systems are needed to supply cattle for harvest year-round. Whereas calf-fed systems pertain to cattle placed directly on feed for harvest following weaning, yearling systems include a forage-based growing program between weaning and finishing. Relative to yearling systems, calf-fed programs may achieve greater feed efficiency, but feeding periods are longer and less carcass weight is produced (Griffin et al., 2007). Profitability between management systems may vary based on seasonal marketing times, production costs and marketing weight. While calf-fed and yearling systems are often implemented with spring-born calves, calves born to later-calving (late-spring, summer, or fall) cowherds that are weaned the following spring are well suited for similar programs. These calves may enter a summer grazing program or be placed in the feedlot and fed a high-concentrate diet until harvest. The age at which calves are weaned may interact with post-weaning management and influence finishing performance and carcass characteristics. Thus, the objectives of this experiment were to evaluate the

impact of age at weaning and post-weaning management system on growing and finishing performance, carcass characteristics, and economics of calves either conventionally-weaned or early-weaned and fed a distillers grains and crop residue diet until the time of conventional weaning.

MATERIALS AND METHODS

All procedures and facilities described in the following experiment were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee. This experiment was conducted over 2 yr at the University of Nebraska-Lincoln Agricultural Research and Development Center (**ARDC**) feedlot near Mead, NE (41° 13' N, 96° 29' W; elevation 369 m) utilizing summer-born crossbred steer and heifer calves ($n = 152$, BW = 231 ± 34 kg). Cattle originated from cowherds maintained in an intensive management (drylot) system year-round located at ARDC and the Panhandle Research and Extension Center (**PHREC**), Scottsbluff, NE (Warner et al., 2015). Data are reported for progeny born during yr 1 (2012) and yr 2 (2013) of that experiment. Calves in yr 1 were of Red Angus \times Red Poll \times Tarentaise \times South Devon \times Devon breeding, and calves in yr 2 were of the same genetic composition plus Simmental and Angus. Approximately one half of the calves annually were weaned from their dams in early-October at 91 ± 18 d of age and fed a distillers grains/corn silage/crop residue based diet until approximately 205 d of age. The remaining calves were weaned in late-January at 203 ± 16 d of age. Following January weaning, all cattle were received at ARDC in mid-February. During initial processing, all cattle were vaccinated for *infectious bovine rhinotracheitis*, *bovine viral diarrhea (types 1 & 2)*, *parainfluenza 3*, and *bovine respiratory syncytial virus* (Bovi-Shield Gold 5[®], Zoetis, Florham Park, NJ), treated for

internal and external parasites (Dectomax[®], Zoetis), and implanted (Ralgro[®], Merck Animal Health, Madison, NJ). The trial was a completely randomized design with a 2 × 2 factorial arrangement of treatments. Each yr, within a calf weaning age cattle were stratified by initial BW and assigned randomly within strata to 1 of 2 post-weaning management treatments with 2 replications (pens, 7-12 animals per pen; based on location of origin) per treatment. Therefore, treatment factors included: 1) calf age at weaning, early-weaned (**EW**) at 91 ± 18 d of age or conventionally-weaned (**CW**) at 203 ± 16 d of age; and 2) post-weaning management system, fast-track (**FT**) or slow-track (**ST**). In the FT system, cattle were adapted to a concentrate finishing diet following a drylot growing period in which cattle were fed for a high (≥ 1.36 kg) ADG. Cattle in the ST system initially were grown in a drylot at a moderate (0.68 kg) ADG, grazed smooth brome grass (*Bromus inermis*) pastures during summer, and were then transitioned to a concentrate finishing diet in the fall.

Upon arrival and assignment to treatments, cattle in both systems entered a growing period (78 d yr 1; 92 d yr 2) ending in late-May. Within each yr, all cattle were fed a common diet (Table 1), but the amount fed daily differed between treatments as the intent was to produce different ADG during the growing period. Cattle in the FT system were offered *ad libitum* access to the growing diet, while ST cattle were limit-fed at an estimated 2.0% of BW (DM). Each yr, heifers were spayed by a licensed veterinarian during the growing period. Upon completion of the growing period, ST cattle were implanted with Revalor-G[®] (Merck Animal Health), treated for parasites (Ivomec[®]; Merial Animal Health, Duluth, GA), and were transported to smooth brome grass pastures at ARDC for summer grazing. Concurrently, FT cattle were treated for parasites

(Ivomec®; Merial Animal Health), implanted with either Revalor-XS® (steers, Merck Animal Health) or Revalor-IH® (heifers, Merck Animal Health), and began adaptation to a concentrate finishing diet (Table 1). Heifers were re-implanted (Revalor-H®, Merck Animal Health) approximately 80 d prior to projected harvest.

Fast-track cattle began the finishing phase (including adaptation diets) in late-May and were harvested in mid-November annually (mean d on finishing diet = 176). Cattle in the ST system grazed smooth brome grass pastures until mid-October (140 d yr 1; 152 d yr 2), then received the same implant and health regimen as FT cattle and began adaptation to the finishing diet. Slow-track heifers were also re-implanted approximately 80 d prior harvest and all cattle assigned to the ST system were harvested in early-April each yr (mean d on finishing diet = 163). Each yr, 12th rib fat thickness was measured via ultrasound on ST cattle approximately 50 d prior to projected harvest. This was done to ensure cattle in both systems were harvested at a common physiological end point (similar fat thickness). Cattle in both systems had *ad libitum* access to a common finishing diet (within yr) which included Optaflexx® (Elanco Animal Health, Greenfield, IN) at 22.2 g/ton DM or 300 mg/hd daily for the last 28 d prior to harvest. Weights were collected over a minimum of 2 consecutive d at both initiation and upon completion of the growing phase to determine gain during that period (Stock et al., 1983). Ending BW from the growing period was used as initial BW for the finishing period for FT cattle. Weights (2 d consecutive) at the end of summer grazing were used as initial finishing BW for ST cattle. Prior to collecting all weights, cattle were limit-fed (2.0% of BW, DM basis) a diet of 50% alfalfa (*Medicago sativa*) hay and 50% wet corn gluten feed (Sweet

Bran, Cargill Corn Milling, Blair, NE) for 5 d to minimize variation in gastrointestinal tract fill (Watson et al., 2013).

All cattle were harvested at a commercial abattoir (Greater Omaha Packing Co., Omaha, NE) once determined finished by visual appraisal. On the day of harvest, HCW and liver abscess scores were recorded. After a 48-h chill, 12th rib fat thickness, USDA marbling score, and LM area were collected. The USDA yield grade was subsequently calculated using the following equation: $2.5 + (6.35 \times 12^{\text{th}} \text{ rib fat thickness, cm}) - (2.06 \times \text{LM area, cm}^2) + (0.2 \times 2.5 [\text{KPH, \%}]) + (0.0017 \times \text{HCW, kg})$ (Boggs and Merkel, 1993). Performance on a carcass adjusted basis was calculated using a common dressing percentage (63%) to determine final live BW, ADG, and G:F.

To evaluate the economics from weaning through harvest between FT and ST post-weaning management systems, a 5-yr (2010 to 2014) analysis was conducted. The analysis evaluated the profitability of each system when cattle were purchased at weaning and ownership retained through harvest. Economics were calculated retrospectively using performance data from the current study, and measurements evaluated included cost of gain (live BW basis), breakeven selling price on both a live and dressed basis, and profit (or loss) when cattle were marketed on either a live, dressed, or grid pricing basis. Performance data and production costs were entered into a spreadsheet (Microsoft® Excel; Redmond, WA) for calculation of economic variables. Projected cost of gains, breakevens, and profits or losses were determined for each experimental unit in the current study based on actual DMI during the growing and finishing phases and final live BW and HCW. Other variables (initial animal purchase price, animal interest, yardage, processing/health, death loss, finished cattle marketing prices) were held constant when

determining economic outcomes for each experimental unit. Breakevens were calculated by dividing total expenses by total weight sold (live or dressed). Costs of gains were calculated by dividing total expenses (minus initial animal price and animal interest) by kg of live BW gained. Profit (or loss) was determined by subtracting total expenses from total revenues.

Initial calf purchase price for placement into the feedlot was determined using the 5-yr national average price for 250 kg feeder steers during the first wk of February (\$160.25 per 45 kg; CattleFax, 2015). The price was discounted \$5.00 per 45 kg given the cattle in the current study were of mixed sex. Interest on cattle was calculated for the number of d from placement until harvest using 5-yr average prime interest rates (3.25%; Kansas City Federal Reserve Bank, 2015). The marketing price of finished cattle was determined from the 5-yr national average live price (CattleFax, 2015) and corresponded to the week of harvest for each post-weaning management system (third wk in November for FT[\$129.67 per 45 kg] and first wk in April for ST[\$124.53 per 45 kg]). Live finished cattle prices were adjusted to a 63% dressing percentage for determination of selling price on a dressed basis (\$205.83 and \$197.67 per 45 kg for FT and ST, respectively). Finished cattle prices on a grid marketing basis were determined using historical premiums and discounts for QG, YG, and HCW as reported by Griffin et al. (2007). The dressed basis selling price was considered to be the initial base carcass price for the grid and the net grid carcass price was calculated (Ward, 2002) separately for FT (\$203.05 per 45 kg) and ST (\$194.64 per 45 kg) systems using biological data from the current study.

Finishing diet costs for each system (\$218.91 per 907 kg, DM) were calculated using the national 5-yr average corn price as reported by USDA (USDA, 2015). Costs for the growing diet (\$200.34 per 907 kg, DM) were calculated using the national 5-yr average corn price and the national 5-yr average price for all hay (USDA, 2015). Feed interest costs were determined using the same interest rate charged for cattle, and were calculated separately for the growing and finishing diet. Summer grazing costs for ST cattle were determined using average cash rental rates for stocker cattle on pasture in eastern Nebraska (\$23.48 per animal per month; Jansen and Wilson, 2015). Yardage was assessed at \$0.40 per animal per d when all cattle were fed the growing and finishing diet in the feedlot, and \$0.10 per animal per d when ST cattle were grazing pasture. Expenses charged for processing/animal health (\$25.00 per animal) and death loss (1.5%) were equal for FT and ST cattle.

Animal performance and carcass data were analyzed as a randomized complete design using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) with pen serving as the experimental unit. Model fixed effects included post-weaning management system, age at weaning, and the system \times weaning interaction. Since the proportion of steers and heifers was unequal among treatments, sex was initially included as a covariate in the model statement for all variables tested and was subsequently removed if not significant. Location of origin and yr were included in all analyses as random effects, and significance was declared at $P \leq 0.05$. Economic data were also analyzed using PROC MIXED of SAS with pen serving as the experimental unit. The fixed effect of post-weaning management system was included in the analysis for all variables tested. Sex

was included as a covariate and location of origin, weaning age and yr were considered random effects.

RESULTS AND DISCUSSION

Cattle performance data during the growing and summer grazing periods are presented in Table 2. No significant post-weaning management by weaning age interactions were observed nor were there significant effects of calf weaning age for all variables tested ($P \geq 0.17$). As designed, the greater ($P < 0.01$) daily DMI by FT cattle resulted in increased ADG ($P < 0.01$) and ending BW ($P < 0.01$) compared to cattle managed in the ST system. While not statistically significant, G:F was numerically improved ($P = 0.19$) approximately 11% for cattle in the FT as opposed to the ST management system. Slow-track cattle gained approximately 0.30 kg daily while grazing summer pasture.

Live finishing and carcass performance variables are presented in Table 3. No significant post-weaning management system by weaning age interactions were observed ($P \geq 0.31$). With the exception of DMI, effects of calf age at weaning on live finishing and carcass performance were not significant ($P \geq 0.35$). Although FT cattle had increased ADG during the growing phase, initial BW at the start of finishing was similar among treatments ($P = 0.89$) due to gain during the summer by ST cattle. Dry matter consumption and ADG were greater ($P < 0.01$) for ST cattle compared with FT cattle. Interestingly, EW cattle also had increased DMI ($P = 0.05$) during finishing compared to CW calves. Feed efficiency during finishing was approximately 4% greater ($P = 0.05$) for cattle managed in the ST system post-weaning. Calves that were managed in the ST system had greater HCW ($P < 0.01$) compared to FT cattle. Longissimus muscle area,

12th rib fat thickness, and calculated YG were not influenced by post-weaning management or calf weaning age ($P \geq 0.27$) suggesting cattle from each system were slaughtered at comparable endpoints. Although calf weaning age was not significant ($P = 0.51$), cattle managed in the ST system had improved marbling ($P = 0.03$) over their FT counterparts.

Results from the current study largely concur with previous research comparing growing and finishing performance between calf-fed and yearling systems (Winterholler et al., 2008; Adams et al., 2010; Griffin et al., 2012) and for cattle weaned at different ages (Phillips et al., 2006). However, a critical distinction between the current and earlier studies is that FT cattle were not considered true calf-feds because they were grown prior to being fed the finishing diet. Conversely, ST cattle were similar to short-yearlings in terms of age at the onset of finishing (14-15 mo). The difference in DMI by design between FT and ST cattle resulted in expected differences in ADG and ending BW upon completion of the growing phase. Gains of ST cattle while grazing summer pasture were lower than previously reported for nonsupplemented steers grazing similar pastures (Greenquist et al., 2009). Slow-track cattle grazed smooth brome grass pastures until mid-October each yr. Thus, declining forage quantity and quality likely limited ADG. Additionally, cattle in the current study were in intensive management (confinement) from birth until weaning and had not previously grazed forage. A lack of grazing experience and familiarity with growing plants may partially explain the decreased performance. This is supported by data from Summers et al. (2014) which demonstrated that replacement heifers developed on corn residue post-weaning had improved performance when subsequently grazing corn residue as a pregnant heifer compared to

females developed on winter range or in a drylot. Those authors reported that an animal's environment early in life and its exposure to certain feeds influences behavior and performance at a later age.

Cattle in the current study were not a true representation of yearlings and calf-feds, but the difference in finishing performance observed between the 2 systems is generally typical for such types of cattle. Work by Griffin et al. (2007) indicated that yearlings consumed more DM during finishing and gained 0.33 kg per d more than calf-feds, but calf-feds were 18% more efficient during finishing. While responses were consistent with that of calf-feds and yearlings, ST cattle had relatively low ADG during summer grazing, and appeared to experience compensatory gain when fed the finishing diet in the fall. Sainz et al. (1995) noted that restricted growth of crossbred steers in the growing phase resulted in increased DMI and ADG during the finishing period. Those researchers indicated that DMI during finishing for cattle restricted during the growing period was 21 to 30% greater than that of non-restricted steers. In our study, ST cattle consumed approximately 25% more DM during finishing than FT. Other researchers (Mader et al., 1989; Ryan et al., 1993) have documented that cattle have increased DMI following growth restriction. Conversely, other authors have observed no difference in DMI following restriction (Coleman and Evans, 1986; Carstens et al., 1991). The greater ADG by ST cattle would be expected given the improvement in DMI (NRC, 1996). Aside from the compensatory response, increased DMI by the ST cattle may be a function of age. Fast-track cattle were approximately 5 mo younger than ST at the start of the finishing period. Previous research suggests that DMI increases in response to greater age (Saubidet and Verde, 1976). Interestingly, early-weaned cattle in the current

study also had slightly greater DMI during finishing regardless of post-weaning system. Phillips et al. (2006) and Grings et al. (2006) reported no difference in finishing DMI for steers weaned at 190 or 240 d of age. Numerous studies (Myers et al., 1999a&b; Story et al., 2000; Barker-Neef et al., 2001) reported that finishing DMI increased as age at weaning advanced. Cattle in those studies were true calf-feds and were adapted to a finishing diet directly upon weaning, unlike our study in which cattle were grown prior finishing. The improved G:F during finishing for ST cattle also challenges previous data for calf-feds and yearlings (Griffin et al., 2007; Winterholler et al., 2008). This may likely be explained by the compensatory gain response. Unlike ST cattle in the current study, ADG of yearlings in the aforementioned studies was not restricted prior to finishing. Sainz et al. (1995) reported that feed efficiency during the finishing phase was improved by limit-feeding during the growing phase.

Similar to previous data with yearlings and calf-feds, the increased final live BW for ST cattle and subsequent greater HCW is likely a result of the extended growing period. Even though initial BW at the start of finishing was similar, the additional backgrounding period may have enabled cattle to increase skeletal growth prior to finishing which may also explain the increased HCW. Carcasses from ST cattle were 33 kg heavier than FT. This agrees with Griffin et al. (2007) and Winterholler et al. (2008) who reported heavier HCW for yearlings than calf-feds by 23 and 55 kg, respectively. While no difference among treatments was observed in the current study, Winterholler et al. (2008) noted increased LM area for yearlings. Adams et al. (2010) observed no difference in LM area between sorted calf-feds or fall yearlings or between unsorted calf-feds and summer yearlings. In agreement with the current study, Winterholler et al.

(2008) also found no difference in 12th rib fat thickness or YG. Yearlings were reported to have less 12th rib fat, but YG was not different from calf-feds (Griffin et al., 2007). Likewise, Adams et al. (2010) observed less 12th rib fat for fall yearlings relative to calf-feds or summer yearlings. In the current study, cattle in both systems were fed to a common compositional end point and 12th rib fat thickness was not different among treatments. Although HCW was greater for ST cattle, it was not sufficient to significantly influence YG. Regarding intramuscular fat deposition, in the studies by Winterholler et al. (2008) and Griffin et al. (2007) marbling score was numerically greater for yearling cattle. In a study comparing three production systems, marbling was similar for calf-feds and fall yearlings, which were greater than summer yearlings (Adams et al., 2010). Other data suggest no difference in marbling (Gill et al., 1993; Sainz and Vernazza Paganini, 2004). Interestingly, when adjusted to a common fat thickness, Griffin et al. (2012) reported increased marbling scores for June-born yearling steers and heifers as compared to calf-feds but no difference between August-born calf-feds and yearlings.

With the exception of DMI, effects of calf weaning age on live performance and carcass variables were not significant. Therefore, economic comparisons were only made between FT and ST management systems. Under the assumptions made in this study, some economic differences were observed between FT and ST systems (Table 4). Breakeven selling prices on both a live and dressed basis were not different ($P \geq 0.74$) between FT and ST cattle. Cost of gain was also not different ($P = 0.25$) between management systems. Regardless of marketing basis (live, dressed, or grid) projected profitability favored FT cattle as compared to ST cattle. When marketed on a live or

dressed basis, FT cattle returned a positive ($P \leq 0.01$) \$110 per animal whereas ST cattle generated a positive ($P \leq 0.01$) \$51 per animal. Marketing finished cattle on a grid pricing basis influenced projected profitability. Profitability for FT cattle declined to \$87.71 per animal or by \$23, yet still greater ($P \leq 0.01$) than cattle managed in the ST system (\$24.85 per animal) which declined \$27.

The primary factors influencing projected breakeven selling prices between FT and ST systems are the differences in feed/grazing expenses and total weight marketed. These same variables plus the price for finished cattle affect cost of gain and profitability. While feed costs during the growing phase were greater for FT cattle due to increased DMI, ST cattle actually incurred greater total expenses mainly due to relatively high summer grass costs relative to summer grass gain and increased feed costs during finishing. Although total weight marketed (live or dressed) was significantly greater for ST cattle, the increased weight was not sufficient to overcome the increased input expense or the decreased fed cattle price realized due to market seasonality. Fast-track cattle were marketed during the fall when 5-yr average fed cattle prices were \$5.14 per 45 kg greater than during spring when ST cattle are sold. Consequently, a stronger fed cattle marketing price, regardless of method, and lower input expenses supported projected profitability for FT. Interestingly, both systems were less profitable when marketed on a grid pricing basis. A greater proportion of ST cattle would grade choice or higher, and thus earn premiums for QG, given the increased marbling. However, discounts were assessed for HCW greater than 454 kg which reduced the ST net grid carcass price. Currently, discounts for heavy carcasses are either small or nonexistent, and premiums and discounts for QG and YG will dictate the economics of marketing cattle on a grid.

While the assumptions made in our study support the economics of FT cattle, current production economics will influence actual profitability of each system.

IMPLICATIONS

These data suggest early-weaning at 91 d of age has little impact on subsequent growing and finishing performance when calves are fed to a similar BW to that of conventionally-weaned calves. The post-weaning management system imposed appears to have greater influence on performance during the growing and finishing periods, as well as other economically relevant traits such as final BW and HCW. While profitability of each system will vary depending on current economies, this study demonstrates the benefit of having different post-weaning calf management strategies. Therefore, post-weaning management decisions should be made based on production and marketing goals.

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Table 1. Ingredient composition of growing and finishing diets fed to all cattle by year¹

Ingredient, %	Growing Diet	
	Yr 1	Yr 2
Corn silage	66.0	--
MDGS ²	30.0	34.0
Sweet Bran ³	--	30.0
Wheat straw	--	31.5
Supplement ^{4,6}	4.0	4.5

Ingredient, %	Finishing Diet	
	Yr 1	Yr 2
MDGS ²	40.0	--
Sweet Bran ³	--	40.0
High-moisture corn	20.5	51.0
Dry-rolled corn	20.5	--
Corn silage	15.0	--
Wheat straw	--	5.0
Supplement ^{5,6}	4.0	4.0

¹All values presented on a DM basis.

²Modified wet distillers grains plus solubles.

³Sweet Bran wet corn gluten feed (Cargill Corn Milling, Blair, NE).

⁴Formulated for 200 mg/animal daily of Rumensin[®] (Elanco Animal Health, Greenfield, IN).

⁵Formulated for 450 mg/animal daily of Rumensin[®] and 90 mg/animal daily of Tylan[®] (Elanco Animal Health, Greenfield, IN).

⁶Supplements contained limestone, trace minerals, and vitamin A,D,E premix.

Table 2. Growing performance of cattle by management system and weaning age

Item	FT ¹		ST ²		SEM	<i>P</i> -value		
	EW ⁶	CW ⁷	EW ⁶	CW ⁷		Sys ³	Wean ⁴	S × W ⁵
Initial BW, kg	231	231	228	238	11	0.78	0.48	0.48
Ending BW, kg	345	344	301	301	12	<0.01	0.92	0.96
ADG, kg	1.39	1.42	0.74	0.74	0.09	<0.01	0.89	0.87
DMI, kg/d	7.7	7.8	4.5	4.5	0.1	<0.01	0.17	0.17
G:F	0.182	0.181	0.164	0.163	0.013	0.19	0.95	0.98
Off Grass BW, kg	--	--	342	346	--	--	--	--
Grass ADG, kg	--	--	0.28	0.31	--	--	--	--

¹FT = fast-track post-weaning management system.²ST = slow-track post-weaning management system.³Fixed effect of post-weaning management system.⁴Fixed effect of calf age at weaning.⁵Post-weaning management system × calf age at weaning interaction.⁶EW = early-weaned at 91 d of age.⁷CW = conventionally-weaned at 203 d of age.

Table 3. Live finishing and carcass performance of cattle by management system and weaning age

Item	FT ¹		ST ²		SEM	P-value		
	EW ⁶	CW ⁷	EW ⁶	CW ⁷		System ³	Weaning ⁴	S × W ⁵
Live Performance								
Initial BW, kg	346	344	342	346	16	0.89	0.78	0.64
Final BW, kg	594	587	642	644	11	<0.01	0.74	0.50
ADG, kg	1.42	1.38	1.84	1.83	0.06	<0.01	0.53	0.74
DMI, kg	9.8	9.6	12.3	11.9	0.4	<0.01	0.05	0.38
G:F	0.145	0.145	0.148	0.153	0.003	0.05	0.35	0.31
Carcass Characteristics								
HCW, kg	374	370	404	406	7	<0.01	0.74	0.50
LM area, cm ²	85.2	84.5	83.9	85.8	4.5	0.87	0.78	0.48
12 th rib fat, cm	1.60	1.63	1.52	1.50	0.13	0.27	1.00	0.70
Calculated YG	3.49	3.55	3.64	3.62	0.30	0.50	0.89	0.80
Marbling ⁸	469	469	541	512	51	0.03	0.51	0.50

¹FT = fast-track post-weaning management system.²ST = slow-track post-weaning management system.³Fixed effect of post-weaning management system.⁴Fixed effect of calf age at weaning.⁵Management system × calf age at weaning interaction.⁶EW = early-weaned at 91 d of age.⁷CW = conventionally-weaned at 203 d of age.⁸Marbling score: 400 = Small, 500 = Modest, ect.

Table 4. Economics of fast-track and slow-track post-weaning calf management systems

Item	System		SEM	<i>P</i> -value
	FT ¹	ST ²		
Breakeven selling price live basis, \$ per 0.45 kg	1.21	1.21	0.03	0.74
Breakeven selling price dressed basis, \$ per 0.45 kg	1.93	1.92	0.04	0.77
Cost of gain live basis, \$ per 0.45 kg	0.94	0.96	0.04	0.25
System profit or loss live basis, \$ per animal	110.30	51.50	35.66	<0.01
System profit or loss dressed basis, \$ per animal	110.51	51.89	35.78	<0.01
System profit or loss grid basis, \$ per animal	87.71	24.85	35.44	<0.01

¹FT = fast-track post-weaning management system.

²ST = slow-track post-weaning management system.

Supplementation of cow-calf pairs grazing smooth brome grass pastures with ethanol by-products and low-quality forages reduces grazed forage intake¹

J. M. Warner, A. J. Doerr, G. E. Erickson, PAS, R. J. Rasby, PAS, and T. J.

Klopfenstein²

Department of Animal Science, University of Nebraska-Lincoln, Lincoln 68583

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² To whom correspondence should be addressed: tklopfenstein1@unl.edu

ABSTRACT

Multiparous, nonpregnant, crossbred (Simmental \times Angus), lactating beef cows ($n = 48$) with spring-born calves at side were used over 3 yr to evaluate supplementing modified wet distillers grains plus solubles (**MDGS**) mixed with low-quality forage on cow and calf performance. In a completely randomized design, cow-calf pairs were stratified annually by pair BW and assigned randomly to one of 2 treatments within strata with 2 replications (pastures) per treatment per yr for 3 yr. Treatments were 1) the recommended stocking rate of 9.46 AUM/ha with no supplementation (**CON**) or 2) double the recommended stocking rate (18.9 AUM/ha) and supplemented with a 30:70 MDGS:cornstalks (DM) mixture (**SUPP**). To replace 50% of grazed forage DM intake, SUPP pairs were fed an average of 1.13% of BW (DM) over the grazing season. SUPP and CON pairs grazed adjacent smooth brome grass pastures for 130 d during the summer growing period. Pasture (4 per year) was considered the experimental unit. By design, cow and calf initial BW was similar ($P \geq 0.18$) between treatments. Gain was similar ($P = 0.19$) between SUPP and CON cows (0.28 vs. 0.19 kg/d, respectively). Ending cow BW was not impacted ($P = 0.46$) by treatment. Similarly, calf gain was not influenced ($P = 0.31$) by supplementation. Calf ending BW tended ($P = 0.08$) to be greater for SUPP than CON calves (228 vs. 213 kg, respectively). In studies where confined cow-calf pairs were fed average quality (IVDMD = 52.9%) forage, DMI was 2.58% of pair BW. Based on these data, CON and SUPP pairs consumed 18.6 and 19.1 kg DM, respectively, of total forage/pair/d. SUPP pairs consumed 7.1 kg/pair/d DM of the supplement, replacing approximately 40% of grazed forage intake. These data suggest mixtures of ethanol co-

products and low-quality forages can be supplemented to replace grazed forage intake of cattle, allowing for increased stocking rate without impacting animal performance.

Key Words: cow-calf pairs, distillers grains, forage replacement, supplementation

INTRODUCTION

Across the Midwest, pasture for beef production systems has become scarce and high priced as grain crop production has expanded (Wright and Wimberly, 2013). Concurrently, crop residues (Ward, 1978) and co-products (Klopfenstein et al., 2008) from corn and ethanol production represent feed resources for beef production that are becoming more abundant, but opportunities to expand their use remain. Investigating alternative management strategies to increase pasture stocking rate and maintain beef production on finite resources is warranted. A practical approach to increase stocking rate may be to replace a portion of the grazed forage by supplementing low-quality crop residues mixed with co-products. Theoretically, replacing approximately 50% of the grazed forage with supplemental feed would support a two-fold increase in stocking rate. Therefore, the objectives of this multi-year experiment were to evaluate the effect of supplementing modified wet distillers grains plus solubles (**MDGS**) mixed with low-quality crop residues to cow-calf pairs grazing smooth brome grass pastures on: 1) cow and calf performance and 2) production economics.

MATERIALS AND METHODS

All procedures and facilities described in the following experiment were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee. Multiparous (8.9 ± 4 yr of age), nonpregnant, crossbred (Simmental \times Angus), lactating

beef cows ($n = 48$) with spring-born calves at side were utilized in a 3 yr experiment conducted on smooth brome grass (*Bromus inermis*) pastures at the University of Nebraska – Lincoln Agricultural Research and Development Center (**ARDC**) located near Mead, NE ($41^{\circ} 13' N$, $96^{\circ} 29' W$; elevation 369 m). In a completely randomized design, cow-calf pairs ($n = 16$ per yr; 4 per pasture) were stratified by total pair BW and assigned randomly within strata to 1 of 2 treatments with 2 replications (pasture) per treatment per yr (total $n = 12$). Treatments consisted of pastures stocked at: 1) the recommended stocking rate of 9.46 AUM/ha without supplementation (**CON**), or 2) double the recommended stocking rate (18.9 AUM/ha) with supplementation (**SUPP**). Pastures were fertilized with 90 kg N/ha in the spring prior to the onset of the trial. Pairs continuously grazed smooth brome grass pastures from early-May until mid-September annually (130 d). Data are reported as pooled across all years for 2011, 2012, and 2013.

Each yr before the beginning of the experiment, cows were located at the University of Nebraska-Lincoln Dalbey-Halleck Research Unit near Virginia in southeast Nebraska. Cows were maintained on dormant smooth brome grass pastures and received *ad libitum* access to alfalfa (*Medicago sativa*) and smooth brome grass hay during calving. Mean calving dates were March 13, March 25, and March 25 for calves born in 2011, 2012, and 2013, respectively. Cows were vaccinated approximately one mo prior to calving against *bovine rotavirus*, *bovine coronavirus*, *escherichia coli*, and *clostridium perfringens* type C (Scour Bos™ 9, Novartis Animal Health, Larchwood, IA). Within 24 h of parturition, calving date, calf birth weight, and sex were recorded, and male progeny were band castrated. Approximately 3 wk prior to the initiation of the trial, all calves were vaccinated against *clostridium chauvoei*, *septicum*, *novyi*, *sordellii*, *perfringens*

types C & D (Ultrabac[®] 7, Zoetis, Florham Park, NJ), and cows and calves were transported from the Dalbey-Halleck Research Unit to ARDC. Cows were marketed for harvest upon completion of the trial each yr. Thus, different cows were used for treatments each yr.

The supplement fed in all years was a 30:70 ratio (DM basis) of MDGS to ground cornstalks designed to replace approximately 50% of the estimated grazed forage DM intake, thereby allowing for the 2-fold increase in stocking rate by the SUPP pairs. Ground cornstalks were chosen as a supplement ingredient to provide rumen fill while MDGS was added at a minimal level necessary to encourage consumption of the low-quality forage. Based on data with confined cow-calf pairs fed average quality (IVDMD = 53%) forage, predicted total forage DMI was calculated as 2.58% of average pair BW throughout the grazing period (Meyer et al., 2012). Therefore, total estimated DMI was calculated retrospectively based on average pair BW for each treatment. It was anticipated grazed forage intake would be greatest early in the grazing season, and decline with seasonal advancement. As a result, pairs were supplemented at 0.6% of BW (DM) at trial initiation with increasing levels throughout the season on a weekly basis to account for 1) declining grazed forage quality and quantity and 2) increasing consumption by the calf. To encourage pairs to begin consuming the supplement, a 50:50 ratio of MDGS to cornstalks (DM) was initially fed with cornstalks increasing and MDGS decreasing by 2 percentage unit increments daily until the 30:70 ratio was obtained. Prior to the beginning of the trial, large-round cornstalk bales were ground (Mighty Giant; Jones Manufacturing Co., Beemer, NE) to pass through a 2.54-cm screen. Ground cornstalks and MDGS were stored in a partially enclosed commodity bay with

concrete flooring before feeding. The supplement was mixed fresh daily using a truck-mounted feed mixer (Roto-Mix[®], Dodge City, KS) and water was added to reduce the DM content to 30% to enhance palatability.

Two-day consecutive cow and calf BW measurements (Stock et al., 1983) were recorded prior to and upon completion of the trial to determine cow BW change and calf gain throughout the grazing period. Prior to collecting weights, pairs grazed a common pasture for a minimum of 5 d to minimize variation in gastrointestinal tract fill (Watson et al., 2013). All pairs were group fed once daily in metal feed bunks with at least 0.9 m of linear bunk space per pair. Bunks were evaluated and feed refusals (if present) were removed and sampled daily. Refusals were sampled for DM determination using a 60°C forced air oven for 48 hr, and DMI was subsequently calculated on a pasture basis.

Data were analyzed using PROC MIXED of SAS (SAS Inst. Inc., Cary, NC) as a completely randomized design with pasture serving as the experimental unit. All analyses included the fixed effect of supplementation treatment, and year considered a random effect. Since the proportion of steer and heifer calves was not equal between treatments, calf sex was initially included as a covariate in the model statement, but was ultimately removed as it was not significant for all variables tested. Significance was declared at $P \leq 0.05$.

To evaluate the economics of supplementing to increase stocking rate, a partial budget analysis was conducted. For the analysis, pasture rental fees, feed prices, and other production costs current as of August 2015 were entered into a partial budget Microsoft[®] Excel (Microsoft[®], Redmond, WA) spreadsheet (Tigner, 2015). The analysis was completed to model a 200 hd cow-calf enterprise located in eastern Nebraska with

the primary assumption that pasture for summer grazing was available for one half (100 pairs) of the cowherd. However, with limited resources, grazing additional rented pasture sufficient for the remaining 100 pair or renting one-half the needed hectares and double stocking with supplementation during the summer grazing season were options considered. For the budget analysis, it was assumed that there would be no decrease or increase in net income between management options because performance and herd inventory would remain unchanged. Therefore, economic differences between management systems would be due to changes in production costs.

An itemized description of changes in expenses are presented in Table 2. Grazing rental fees for eastern Nebraska were valued at \$64.55 per pair per month (\$2.15 per d) (Jansen and Wilson, 2015). Freight expense for shipping cattle to and from pastures was calculated at \$2.48 per kilometer (\$4.00 per loaded mile) assuming 3 semi-truck loads for 100 pairs. It was assumed that pasture for 100 pairs could be rented 16.1 kilometers (10 miles) away or pasture for 50 pairs could be rented only 8 kilometers (5 miles) away. Feed costs were compiled using data from weekly published feed price reports (USDA, AMS). Freight expense for feed delivery was assessed at \$5.00 per 907 kg (2,000 lb). Costs of grinding baled cornstalk residue were calculated at \$12.00 per 907 kg. Feed needs included a 5% shrink for MDGS and cornstalks. Yardage expense associated with checking, maintaining fence, and caring for cattle was charged at \$0.10 per pair per day for cattle on pasture, and \$0.20 per pair per day for cattle supplemented on pasture to account for increased equipment costs of mixing and delivering the feed. However, equipment necessary for feeding was considered already owned by the enterprise. It was assumed that supplement would be fed in a bunk. Therefore, bunks were considered

purchased at a total one-time cost of \$10,000 but were prorated across 100 pairs per yr for 10 yr. Additional costs associated with breeding and salt/mineral supplementation were not considered to be different between management systems, thus were not included in the analysis.

RESULTS AND DISCUSSION

Cattle performance and supplement intake data are presented in Table 1. By design, cow age and initial BW were not different between treatments ($P \geq 0.69$). Although not statistically significant ($P \geq 0.19$), both ending cow BW and gain were numerically greater for SUPP than CON cows. Cows receiving supplement had 0.09 kg per d greater ADG than CON cows. Calf age at the onset of the trial, initial BW and ADG were not significantly different ($P \geq 0.18$) between SUPP and CON pairs. However, a numerical improvement in ADG resulted in a tendency ($P = 0.08$) for greater ending BW for SUPP calves. While no attempt was made to measure the amount of supplement consumed by the calves, calves were observed at the bunk with their dams and appeared to be eating supplement daily.

The results observed in the current study generally concur with that reported by other investigators. Cows double stocked and supplemented with a 30:70 ratio (DM) of wet distillers grains plus solubles (**WDGS**) and wheat straw tended to have greater ADG compared to those grazing at a recommended stocking rate in similar work on upland native Sandhills range (Nuttelman et al., 2010). Interestingly, calf performance was not affected by supplementation. In a different study by the same authors, both cow and calf ADG were improved by feeding a 45:55 ratio of WDGS and grass hay to double stocked pairs. The researchers attributed the improvement in calf ADG to increased milk

production by the dam from intake of a high quality feed, direct consumption of the supplement by the calves, or a combination of both factors. In agreement, nonpregnant, nonlactating cows grazing smooth brome grass had numerically greater ADG when double stocked and supplemented (Doerr et al., 2012). Likewise, ADG of yearling steers grazing upland native Sandhills range at twice the recommended stocking rate was improved by supplementing a mixture of 60% forage (wheat straw or grass hay) and 40% WDGS (DM basis; Villasanti et al., 2011). The supplementation rate in the current study was designed to replace grazed forage intake rather than improve performance. The small numerical increase in performance by SUPP pairs is logical, given the supplement would contain more energy than the grass it replaced. Data from Watson et al. (2012) indicated % IVDMD of smooth brome grass diet samples decreased from nearly 69% in May to 51% in September, averaging approximately 59%. This is slightly lower than the TDN content of the supplement in the current study (63% TDN, DM basis).

Across all 3 yr, average total pair BW was 722 and 737 kg for CON and SUPP pairs, respectively. Based on these BW and data from Meyer et al. (2012), total estimated DMI was calculated to be 18.6 and 19.1 kg per pair daily for CON and SUPP, respectively. For SUPP pairs, supplement DMI averaged 7.1 kg daily throughout the season, and by difference grazed forage intake was calculated as 11.9 kg per d. This suggests the supplement reduced estimated grazed forage intake by 37%, or 0.45 kg of supplement replaced 0.43 kg of grazed forage. Similar research conducted in the Sandhills (Nuttelman et al., 2010) with cow-calf pairs demonstrated grazed forage replacement values of approximately 40 to 50% when a 30:70 ratio (DM) of WDGS and wheat straw was fed. Forage disappearance per cow-calf pair per d was not influenced by

supplementation of a 45:55 ratio of WDGS and grass hay in other work by Nuttelman et al., 2010. Doerr et al. (2012) noted that a blend of 35% by-product and 65% wheat straw (DM) decreased smooth brome intake by 48%. Range forage intake of double stocked yearling steers was reduced 44 to 54% by feeding a low-quality forage and WDGS (Villasanti et al., 2011). However, substitution effects on forage intake appear to be dependent on supplement characteristics. Grazed forage intake was not reduced when yearling steers were supplemented only dried distillers grains plus solubles in studies by Gustad et al. (2008) and Stalker et al. (2012). While previous work (MacDonald et al., 2007; Griffin et al., 2012) has suggested a substitution effect on forage intake when distillers grains are fed in forage-based diets, reductions in forage intake have not proven sufficient to increase stocking rate two-fold (Stalker et al., 2012). This indicates using fibrous low-quality forages in the supplement is essential to reducing voluntary grazed forage DMI and achieving significant forage replacement rates. This concurs with the well-established concept that intake of forage-fed cattle is regulated by rumen fill and digesta passage (NRC, 1996).

Based on current production costs and analysis assumptions, leasing pasture for 50 pairs and double stocking with supplementation as opposed to leasing additional grazing land for all 100 pairs resulted in a gain of \$936 (Table 2). This is primarily due to the relationship between pasture rental fees and feed prices. At a pasture rental fee of \$64.55 per month, the cost per cow-calf pair per d equates to \$2.15. At feed prices (\$ per 907 kg, including freight and grinding) of \$72.50 and \$77 for MDGS and cornstalks, respectively, the cost of the supplement per pair per d equals \$0.81. Thus, supplementation would be profitable if the cost of the supplement is less than the cost of

the grass being replaced. At the assumed price levels and production costs, double stocking and supplementing was more profitable.

IMPLICATIONS

Supplementing cow-calf pairs grazing smooth brome grass pastures with a mixture of ethanol co-products and corn residue reduced estimated grazed forage intake without impacting animal performance. This may be a feasible management practice to increase stocking rate when pasture for grazing is limited. This technique may be most applicable in higher-rainfall areas which support the growth of productive cool-season grass species such as smooth brome grass than on rangelands in more arid climates, because there are likely fewer potential risks of overgrazing. Likewise, in such areas ethanol co-products and crop residues are typically more abundant while increased demand for pasture grazing may exist. The price relationship between pasture and feed supplement ingredients dictates the economics of supplementation to increase stocking rate.

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Table 1. Performance of cow-calf pairs grazing smooth brome grass pastures by treatment

Item	Treatment		SEM	<i>P</i> -value
	CON ¹	SUPP ²		
Pastures (n)	6	6		
Cow				
Age, yr	8.6	9.0	0.7	0.69
Initial BW, kg	563	560	11	0.73
Ending BW, kg	588	597	19	0.46
ADG, kg	0.19	0.28	0.06	0.19
Calf				
Age, d	47	50	3.3	0.48
Initial BW, kg	80	88	5	0.18
Ending BW, kg	213	228	19	0.08
ADG, kg	1.03	1.08	0.08	0.31
Grazed forage intake ³ , kg DM/pair	18.6	11.9		
Supplement intake, kg DM/pair	--	7.1		
Total DMI ³ , kg/pair	18.6	19.1		

¹Pairs grazed at recommended stocking rate (9.46 AUM/ha) without supplementation.

²Pairs grazed at double the recommended stocking rate (18.9 AUM/ha) and received 50% of estimated daily intake of 30:70 MDGS:cornstalks mixture, DM.

³Calculated values.

Table 2. Partial budget analysis of supplementing cow-calf pairs to replace forage intake

Decreases in cost		Increase in cost	
Item	Amount	Item	Amount
No pasture rental for 100 pairs 150 days @ \$2.15 per day	\$32,250	Pasture rental for 50 pairs 150 days @ \$2.15 per day	\$16,125
No cattle freight for rented pasture \$2.48 per loaded km @ 16.1 km 3 loads, 2-ways	\$240	MDGS (\$72.5 per 907 kg) Cornstalks (\$77 per 907 kg)	\$5,380 \$7,431
No expense for checking, fence care \$0.10 per pair per day	\$1,500	Expense for checking, fence, care \$0.20 per pair per day	\$3,000
		Cattle freight for rented pasture \$2.48 per loaded km @ 8 km 3 loads, 2-ways	\$119
		25 bunks, \$400 per bunk, 10 yr lifetime	\$1,000
Total	\$33,990	Total	\$33,054
Change In Net Income	\$936		

**Estimation of profitability of an intensively managed cow-calf production system
and the economic sensitivity of profitability to changes in feed costs, feeder cattle
prices, replacement female costs, and reproductive rate**

J. M. Warner,* K. Brooks,† R. J. Rasby,* PAS, and T. J. Klopfenstein¹*

*Department of Animal Science, University of Nebraska-Lincoln, Lincoln 68583

†Department of Agricultural Economics, University of Nebraska-Lincoln, Lincoln 68583

¹ To whom correspondence should be addressed: tklopfenstein1@unl.edu

ABSTRACT

Our objective was to predict profitability through weaning of a yr-round intensively managed (confined) cow-calf production system and determine the sensitivity of profitability to changes in production prices and weaning rates. Production parameters were obtained using data from a summer-calving cowherd maintained in intensive management yr-round in which calves were weaned and marketed at 7 mo of age. To meet nutrient requirements, a common diet (60:40 distillers grains:crop residue, DM) was fed with amounts varying for nonlactating cows (6.8 kg DM/cow daily) and cow-calf pairs (10.4 kg DM/pair daily). Profitability per cow was determined by subtracting total annual cow costs from gross revenue, using initial base prices and then under varying costs for replacement cows, calf and feed prices, and weaning rates. At varying prices for replacement cows (\$1,600 - \$3,000 per cow) and weaning rates (75-95% weaned of exposed), losses \geq \$100 per cow per yr were modeled at base calf and feed prices. Positive returns (\geq \$18 per cow per yr) were modeled at steer calf marketing prices \geq \$2.56 per 0.45 kg, when other inputs were held at base prices. At an 85% calf crop weaned per cow exposed for breeding, positive returns were modeled at calf prices \geq \$2.36 per 0.45 kg and the price of corn is \leq \$3.50 per bu. In all analyses, greater returns were projected as weaning percentage increased, verifying the importance of minimizing calf losses. Data indicate positive returns may be realized for intensive management production systems utilizing distillers grains and crop residues, but the economic feasibility of such a system will be dependent on price relationships for feed and calves and cowherd reproductive performance.

Key Words: beef cow, economics, intensive, profitability, system

INTRODUCTION

Profitability in any beef cow-calf enterprise is ultimately a function of input costs and generated returns. Achieving operation profitability requires a clear understanding and analysis of the various economic factors driving profitability. Feed cost has frequently been reported as the greatest variable cost associated with cow-calf production (Rasby et al., 1990; May et al., 1999). Thus, considerable effort has historically been placed on evaluating methods to reduce harvested or purchased forages and feeds, but the price of forages/feeds relative to other inputs (i.e. grazing costs, land values) varies significantly depending on yr and location.

While expenses associated with maintaining a cowherd are a combination of fixed and variable costs, returns generated through the sale of feeder calves are a function of reproductive rate, and calf value. Reproduction, expressed as calves weaned per female exposed for breeding, influences profitability of the cow-calf system because the breeding female incurs all expenses of calf production. Furthermore, Griffin et al. (2012) noted that seasonal variability exists for cattle prices depending on size and class, potentially creating opportunities for production systems to match the timing of marketing to periods of stronger market prices. Marketing weaned calves and cull livestock in the fall when prices are seasonally the weakest often occurs in the typical spring-calving system. Likewise, Stockton et al. (2007) documented that moving the calving season changes the timing of production and marketing which may prove economically beneficial.

In major cow-calf production regions, extensive pasture-based systems have historically been most common. Recently, numerous economic factors have led to strengthened land values and stimulated the conversion of pasture and other grasslands to cropland (Wright and Wimberly, 2013). When such changes in land use are combined with other events that decrease forage availability (i.e. drought), the price of grass and other forages increases and the cowherd must be maintained using alternative resources. However, increased corn and ethanol production in major crop production areas has resulted in a greater abundance of other feedstuffs, primarily residues and distillers grains. Alternative cow-calf production systems involving partial or total intensive management (confinement) of cows utilizing crop residues and distillers grains may be viable alternatives to conventional cow-calf systems. While production data are limited on intensive cow-calf management as an alternative to conventional systems, complete economic analyses are also needed to assess system profitability. To our knowledge, limited evaluations of an intensively managed cow-calf system designed around an abundance of resources from corn production have been conducted. The objectives of this analysis were to model profitability through the weaning phase of production of an intensively managed cow-calf production system located in the Midwest and evaluate the sensitivity of profitability to changes in annual cow feed costs, feeder cattle prices, replacement female purchase costs, and reproductive rate (number of calves weaned per cow exposed for breeding).

MATERIALS AND METHODS

Production System

Production data were obtained from a study conducted by Warner et al. (2015) in which a beef cow-calf herd was confined to earthen feedlot pens yr-round. That trial was conducted over 2 yr at both the University of Nebraska-Lincoln Agricultural Research and Development Center (**ARDC**) feedlot located near Mead, NE and the Panhandle Research and Extension Center (**PHREC**) feedlot at Scottsbluff, NE. In that study, multiparous (4.6 ± 1 yr of age), crossbred (Red Angus \times Red Poll \times Tarentaise \times South Devon \times Devon), cows (total $n = 156$) calved during summer (mean calving date = July 15) and calves reached a conventional weaning age of approximately 7 mo in February. The logic for summer calving in this system was improved pen conditions during June and July, and calves would be weaned and marketed in the spring into a historically stronger market (Stockton et al., 2007). The cowherd was fed a base diet as a TMR to meet nutrient requirements and the amount of DM offered varied throughout the yr based on stage of production. Primary diet ingredients included wet or modified distillers grains plus solubles (**DGS**), ground crop residue (cornstalks or wheat straw), and a supplement to deliver minerals and vitamins. These feed ingredients would be considered typical for any intensively managed cow-calf operation located in the major corn production regions of the Midwest. Multiparous pregnant cows were purchased annually in the spring as replacement females and all progeny were marketed at weaning. Therefore, the system modeled was considered terminal and replacement cows were assumed to be purchased. Because calving and weaning occurred during summer and winter, respectively, cows were evaluated for pregnancy status and all cull animals sold at the time of weaning.

Economic Analysis

A Microsoft® Excel (Microsoft®, Redmond, WA) spreadsheet budget was constructed to model profitability of the intensively managed cow-calf system. Base production parameters and economic assumptions made are presented in Tables 1 and 2, respectively. An arbitrary number of cows (100) were used as an initial inventory of exposed females each yr. Data from Warner et al. (2015) were used to establish length of the breeding season and calf age at weaning. In that study, calves were either early-weaned at an average age of 91 d or conventionally-weaned at an average age of 203 d. Given the efficiency of feed use was not significantly different between nursing pairs and weaned cows and calves, the current analysis evaluated the system in which calves were weaned and marketed at 7 mo of age.

Prices for all feeds were entered into the spreadsheet on an as-is basis. Base distillers grains price was calculated as 100% of the value of \$3.50/bu corn on a DM basis. Base price for crop residue was \$50 per 907 kg based on reported values as of September 2015 (USDA, 2015). Additional costs added to feeds included \$5 per 907 kg for delivery, \$15 per 907 kg for grinding of baled crop residue, and 5% shrink on all ingredients. Feed prices were converted to a 100% DM basis for calculation of ration costs. Interest was charged to both cows and bulls based on average lifetime value under the assumption that cattle required financing (Kansas City Federal Reserve Bank, 2015). Base replacement female price was determined using the Midwest average price for bred cows as of September 2015 (CattleFax, 2015). This price was multiplied by the average female replacement rate to determine the capital cost of the replacement female. The average base cull cow market price was determined using the national 5-yr average price from 2010 to 2014 (CattleFax, 2015) and corresponded to the first wk of February as cull

animals would be marketed at that time. This price was increased \$0.20 per 0.45 kg to establish the average base cull bull market price. Base market BW for cull cows and bulls were assessed at 567 and 907 kg, respectively. Marketing costs were charged at \$30 per cow per yr. Likewise, expenses for animal health and identification were assessed at \$30 per cow per yr. Yardage was charged at a common rate for cows and bulls to cover expenses for labor, equipment, utilities/fuel, and land/loans (Jensen and Mark, 2010).

Bulls were considered purchased by the cowherd owner at a one-time base cost and maintained in confinement yr-round. The average productive life of bulls was considered to be 4 yr and a 1:25 bull:cow ratio was assumed. Costs of bull ownership were calculated by dividing initial purchase cost by the number of cows serviced over the bull's lifetime. Feed amounts for bulls were considered to be equal to that for either lactating or nonlactating cows depending on if bulls were in service. Because the cow was considered the productive unit, all bull expenses for feed, yardage, and interest were prorated so each cow was charged $1/25^{\text{th}}$ of the cost of the bull.

Base calf marketing BW was assessed using data from Warner et al. (2015). The average base market price for 204 kg feeder steers was determined using the national 5-yr average price from 2010 to 2014 (CattleFax, 2015) corresponding to the first wk of February when calves would be sold. A discount of \$0.10 per 0.45 kg was applied to derive the average base price for heifers. Total revenues from the sale of weaned calves were calculated using the percentage calf crop weaned relative to the number of exposed females, weaning BW, and corresponding prices for steers and heifers assuming each sex comprised 50% of the resulting calf crop. A base value of 85% was assessed for calf

crop weaned based on cows exposed for breeding. Total annual costs per cow per yr were determined as the sum of feed, interest, and yardage for cows and bulls, bull ownership costs, capital costs of the replacement female, animal health/identification, and marketing less credits for cull animals and manure. Credits for cull animals were calculated by multiplying the value of the cull animal by replacement rate adjusted for death loss. Cows were credited \$50.00 per cow per yr from the fertilizer value of manure produced, which is similar to that reported by Anderson et al. (2013). Total annual costs per cow per yr were multiplied by the number of cows exposed to calculate total costs for the system. Total system costs were subtracted from total revenues to determine net system profit or loss, which was then divided by the number of cows exposed to calculate profit or loss on a per cow per yr basis.

System profitability was first modeled using initial base input prices and then under 4 different price and production analyses. In each analysis, two price or production parameters were changed at a time, while remaining parameters were held constant at initial base values. Therefore, projected profitability was influenced solely by the change in the parameters selected. The first analysis evaluated the effect of varying both the cost of replacement females (\$1,600 - \$3,000 per cow) and the percentage of calves weaned per cow exposed (75 – 95%) on profitability. In the second analysis, both calf marketing price (\$1.76 - \$3.16 per 0.45 kg) and weaning rate (75 – 95%) were varied. The price of distillers grains in relation to different corn price levels (85, 100, or 115% of \$2.00 - \$5.00 per bu corn) and weaning rate (75 – 95%) were altered in the third analysis. The final analysis evaluated the influence of both distillers grains (85, 100, or 115% of \$2.00 - \$5.00 per bu corn) and feeder calf prices (\$1.76 - \$3.16 per 0.45 kg) on profitability.

RESULTS AND DISCUSSION

For the yr-round intensively managed cow-calf system, modeled profitability was -\$346 per cow per yr under base price levels. This suggests that if 204 kg steers are priced at \$1.76 per 0.45 kg and base inputs and prices held constant, revenue generated is clearly not sufficient to overcome system costs. However, the costs of replacement females, the value of calves, feed prices, and reproductive rates collectively have the greatest influence on cowherd economics irrespective of production system. Thus, these factors were evaluated in the current analysis.

Replacement females represent a significant capital investment, and the cost to bring replacements into the cowherd has important ramifications on system profitability (Meek et al., 1999). The purchase price for replacement cows dictates interest expense and the share of the capital cost of the replacement that is allotted to the remaining cows in the herd. The difference between the capital cost of the replacement and the cull cow credit value is depreciation. At base price levels, the capital cost of the replacement represents $\geq 30\%$ of the total annual cow cost. Therefore, replacement cow purchase values were priced against different weaning rates to evaluate profitability (Table 3). Regardless of cow purchase price, profitability was most negative at 75% calf crop and improved as calf crop percentage increased. This is because weaned of exposed percentage directly influences gross revenue. As replacement cow price decreased from \$3,000 to \$1,600 per cow, profitability improved regardless of weaning percentage largely because the capital cost of the replacement female declined. However, substantial losses were modeled in all production and replacement cow price scenarios when prices for feed, calves and other parameters were held constant at base values. This indicates

that while female replacement cost is an important determinant of profitability, overall profit potential may be less sensitive to changes in replacement cost.

Clearly, feeder calves represent the primary revenue source in any cow-calf system, and the price received significantly affects revenue of the operation. Various calf marketing prices were priced against different weaning rates to evaluate profitability when all other input parameters and price levels were held constant at base (Table 4). As observed with replacement cow prices, projected profitability was the least at 75% calf crop, and improved as percentage weaned per cow exposed increased regardless of calf price level. Likewise, irrespective of weaning rate, profitability improved as calf prices increased. At a base steer calf price of \$1.76 per 0.45 kg, and heifer price adjusted accordingly, substantial losses were modeled for the intensively managed cow-calf system at any weaning rate. At a price of \$2.56 per 0.45 kg, losses moderated and positive returns were realized at high weaning rates. At price levels \geq \$2.76, strong profits were modeled, even at low weaning rates. An important observation from these data is that positive or negative movements in calf price significantly impact overall profitability of the system much quicker than changes in replacement cow prices. Logically, this indicates that potential profitability of an intensively managed system will largely be a function of the price received for calves because of the direct effect it has on gross revenue.

Returns to any intensively managed cow-calf system which relies on harvested forages and feeds to meet cowherd nutrient requirements are strongly dependent on feed price. For the system analyzed in the current study, primary feed ingredients include distillers grains and baled crop residue, and total feed expenses represented \geq 50% of

total annual expenses. Distillers grains represent the majority of the diet and the price of distillers grains has historically been a function of corn price. To investigate the impact of feed price and weaning rate on modeled profitability, the price of distillers grains as a percentage of varying corn price levels was manipulated at different weaning rates (Table 5). Only the price of distillers grains was evaluated because the price of crop residue tends to vary considerably by region and yr. Distillers grains were priced at either 85, 100, or 115% of corn price (DM basis), when corn was priced from \$2.00 to \$5.00 per bu. Similar to the initial two analyses, all other prices and inputs were held constant at base. As observed in the first two analyses, profitability improved as weaning rate increased from 75 to 95% regardless of the price of distillers grains. Not surprisingly, profitability across all weaning rates improved as the price of distillers grains decreased. However, when all other prices and inputs were held at base values, the magnitude of decline of distillers grains price was not sufficient to generate a positive return, even at a corn price of \$2.00 per bu. This indicates that if 204 kg steer calves are priced at \$1.76 per 0.45 kg, revenues from calves are not sufficient to cover production costs in an intensively managed system, even if distillers grains are priced in relation to \$2.00 per bu corn.

The price of calves has the greatest impact on gross revenue of the system, and distillers grains represent the greatest component of overall feed costs. Perhaps evaluating the response in profitability to concomitant changes in both calf and distillers grains price will provide the most information regarding economic feasibility of the intensively managed system (Table 6). In this analysis, the price of distillers grains as a proportion of corn price was varied against steer calf prices of \$1.76 to \$3.16 per 0.45 kg

with all remaining inputs and values constant at base levels. As expected, projected profitability improves as calf price increases, irrespective of distillers grains price. At calf prices of \$1.76 to \$2.16 per 0.45 kg, moderate to large losses per cow per yr were projected depending on the price of distillers grains. At a calf price of \$2.36 per 0.45 kg, positive returns were projected, but only at low distillers grains prices. With calf prices beyond \$2.36 per 0.45 kg, strong profitability was modeled, particularly at corn price levels of \$3.50 per bu or lower. Even with the price of corn near \$4.50 or \$5.00 per bu, considerable profits were generated at high calf price levels. For an intensively managed cow-calf system, potential profitability will be greatly impacted by calf and feed prices and changes in price levels in either one or both commodities will strongly affect economic outcomes. Collectively, these data suggest that under the assumptions made in this study, positive returns to an intensively managed cow-calf system may be realized if calves are priced above \$2.36 per 0.45 kg and the price of corn is \$3.50 per bu or less.

Additional expenses contribute to total annual cow costs in any production system. Changes in such costs were not evaluated in the current analyses, but have critical effects on economic outcomes. For example, bulls represent a significant investment for a cowherd and add \$60 per cow per yr in ownership cost alone at the base bull purchase price used in the current study. Expenses for cattle marketing and animal health/identification each represent an additional \$30 per cow per yr, but must be accounted for in an operation budget. Yardage is an important consideration in intensively managed cow-calf systems. At \$0.35 per d, yardage charged per cow unit is approximately \$133 annually if cows are in intensive management yr-round. It is necessary to include yardage in a cowherd economic analysis, or otherwise directly

account for those costs that are included in a yardage value (labor, equipment, utilities/fuel, land/loans). The value used in the current study (\$0.35 per d) may be greater than usually assessed for many operations, but is consistent with that reported for commercial feedlots (Jensen and Mark, 2010) and intensively managed cowherds (Anderson et al., 2013).

While economic analyses of conventional cow-calf production systems are common in the literature (Anderson et al., 2005; Stockton et al., 2007; Payne et al., 2009), studies involving alternative intensively managed systems are limited. Certainly, this is because intensively managed systems have historically been less common. Three yr of data directly comparing intensively managed and conventional cow-calf production in North Dakota indicated that total net cost per pair per yr was approximately \$22 greater for intensively managed pairs (Anderson et al., 2013). This equated to a \$0.23 advantage for total cost per 0.45 kg of calf weaned for the conventional system. In another recent analysis, Close (2015) estimated production costs and returns for total intensive management systems at 3 different price levels (\$2.20, \$2.70, or \$3.50 per 0.45 kg) for 250 kg calves sold at weaning. If aged cows were purchased as replacements and produced 2 calves, returns above costs were reported from \$88 to \$800 per cow per yr depending on calf price received. If young females were purchased as replacements, producing 7 calves on average, profitability per cow per yr ranged from -\$22 to \$693. While these data suggest that strong profits may be realized, there are several important distinctions between the current analysis and the analysis by Close (2015). In that analysis, costs for yardage, capital cost of replacement females, and marketing expenses were not included when calculating total annual cow costs. However, of greater

importance, Close (2015) assumed a calf weaning BW of 250 kg as compared to 204 kg based on published data in the current analysis, and calf prices were greater than this analysis resulting in greater projected revenue.

An important observation from these data is that projected profitability always improves as percentage weaned of exposed increases, regardless of the price of cattle or feed. This demonstrates the importance of achieving a high weaning percentage to maximize profits and minimize losses. For example, if calves are priced at \$2.76 per 0.45 kg, the difference between 80 and 85% weaned of exposed is \$61 per cow per yr. These data can be used directly by the producer to determine what level of reproductive efficiency is needed to obtain a positive return at given feed and calf prices. Likewise, if calf and feed prices can be projected, then returns can be estimated at various reproductive rates. For instance, if distillers grains is priced at 100% the value of \$3.50 per bu corn, and calves are priced at \$2.76 per 0.45 kg, then a profit of \$38 per cow would be realized at an 85% calf crop. A decrease or increase in reproductive rate would influence this estimate accordingly. This analysis is one of only few conducted on a total intensively managed cow-calf system relying principally on feed resources from corn and ethanol production. It provides a model for producers to estimate profitability of such a system when production and price parameters are known.

IMPLICATIONS

Cow-calf systems are complex, but the economic feasibility of a cow-calf production system is ultimately a function of the costs of replacement females, the value of calves, feed prices, and reproductive rates. These same fundamentals also determine profitability of alternative systems centered around feeding cows in intensive

management. Intensively managed production systems designed to utilize feedstuffs from corn and ethanol production will be influenced heavily by the price of those resources. If production inputs and price parameters are known, profitability of the enterprise can be estimated. It is important for producers to consider all components that affect economics when evaluating alternative production systems.

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Table 1. Base annual production inputs for intensively managed system

Item	Value	Unit
Total mature cow inventory exposed for breeding	100	cows
Length of breeding season	60	d
Average calf age at weaning	210	d
Average productive bull lifetime	4	yr
Cows serviced over bull's lifetime	100	cows/bull
Average cull cow market BW	567	kg
Average cull bull market BW	907	kg
Calf crop weaned based on cows exposed	85	%
Average calf weaning BW	204	kg
Average female replacement rate	15	%
Cow DMI, nonlactating period ¹	6.8	kg/d
Cow DMI, lactating period ¹	10.4	kg/d
Bull DMI, breeding period ²	10.4	kg/d
Bull DMI, nonbreeding period	6.8	kg/d

¹Based on feeding a 60:40 distillers grains:crop residue diet (DM basis).

²Assuming equal DMI to that of cows during the breeding season.

Table 2. Base production input and marketing prices

Item	Value	Unit
Average bull purchase price	6,000	\$/bull
Cattle interest rate	3.5	%
Average cull cow market price	0.74	\$/0.45 kg
Average cull bull market price	0.94	\$/0.45 kg
Manure value credit	50	\$/cow/yr
Animal health and identification expenses	30	\$/cow/yr
Marketing expenses	30	\$/cow/yr
Cow yardage	0.35	\$/cow/d
Bull yardage	0.35	\$/bull/d
Average steer calf market price	1.76	\$/0.45 kg
Average heifer calf market price	1.66	\$/0.45 kg
Average purchase cost of replacement cow	2,300	\$/cow
Average WDGS ¹ price ² as-is	51.47	\$/907 kg
Average baled crop residue price	50.00	\$/907 kg
Average supplement price	400.00	\$/907 kg

¹WDGS = wet distillers grains plus solubles.

²Equal to 100% the price of \$3.50/bu corn DM basis.

Table 3. Projected profitability (\$ per cow per yr) by replacement cow purchase price and percentage of calves weaned per cow exposed¹

Price, \$/cow	% weaned of exposed				
	75	80	85	90	95
3,000	-540	-502	-463	-425	-387
2,900	-523	-485	-447	-408	-370
2,800	-507	-468	-430	-392	-353
2,700	-490	-452	-413	-375	-336
2,600	-473	-435	-396	-358	-320
2,500	-456	-418	-380	-341	-303
2,400	-440	-401	-363	-325	-286
2,300	-423	-385	-346	-308	-269
2,200	-406	-368	-329	-291	-253
2,100	-389	-351	-313	-274	-236
2,000	-373	-334	-296	-258	-219
1,900	-356	-318	-279	-241	-202
1,800	-339	-301	-262	-224	-186
1,700	-322	-284	-246	-207	-169
1,600	-306	-267	-229	-191	-152

¹All other prices and inputs held at base values.

Table 4. Projected profitability (\$ per cow per yr) by calf marketing price and percentage of calves weaned per cow exposed¹

Price, \$/0.45 kg ²	% weaned of exposed				
	75	80	85	90	95
3.16	51	121	191	261	331
2.96	-17	49	114	180	245
2.76	-84	-23	38	99	160
2.56	-152	-95	-39	18	74
2.36	-219	-167	-115	-63	-11
2.16	-287	-239	-192	-144	-97
1.96	-354	-311	-268	-225	-182
1.76	-422	-383	-345	-306	-268

¹All other prices and inputs held at base values.

²Steer price only, heifer price discounted \$0.10 per 0.45 kg.

Table 5. Projected profitability (\$ per cow per yr) by distillers grains price as a proportion of corn price and percentage of calves weaned per cow exposed¹

Corn Price, \$/bu	% weaned of exposed				
<u>5.00</u>	75	80	85	90	95
115%	-629	-591	-552	-514	-475
100%	-560	-522	-483	-445	-406
85%	-491	-452	-414	-375	-337
<u>4.50</u>					
115%	-576	-538	-499	-461	-422
100%	-514	-475	-437	-398	-360
85%	-451	-413	-375	-336	-298
<u>4.00</u>					
115%	-523	-485	-446	-408	-369
100%	-468	-429	-391	-352	-314
85%	-412	-374	-335	-297	-258
<u>3.50</u>					
115%	-470	-431	-393	-355	-316
100%	-421	-383	-344	-306	-268
85%	-373	-334	-296	-258	-219
<u>3.00</u>					
115%	-417	-378	-340	-307	-263
100%	-375	-337	-298	-260	-221
85%	-334	-295	-257	-218	-180
<u>2.50</u>					
115%	-364	-325	-287	-248	-210
100%	-329	-291	-252	-214	-175
85%	-294	-256	-217	-179	-141
<u>2.00</u>					
115%	-311	-272	-234	-195	-157
100%	-283	-244	-206	-167	-129
85%	-255	-217	-178	-140	-101

¹All other prices and inputs held at base values.

Table 6. Projected profitability (\$ per cow per yr) by distillers grains price as a proportion of corn price and calf marketing price¹

Corn Price, \$/bu	Calf Price, \$/0.45 kg ²							
5.00	1.76	1.96	2.16	2.36	2.56	2.76	2.96	3.16
115%	-552	-476	-399	-323	-246	-170	-93	-17
100%	-483	-407	-330	-254	-177	-101	-24	52
85%	-414	-337	-261	-184	-108	-31	45	122
4.50								
115%	-499	-423	-346	-270	-193	-117	-40	36
100%	-437	-360	-284	-207	-131	-54	22	99
85%	-375	-298	-222	-145	-69	8	84	161
4.00								
115%	-446	-370	-293	-217	-140	-64	13	89
100%	-391	-314	-238	-161	-85	-8	68	145
85%	-335	-259	-182	-106	-29	47	124	200
3.50								
115%	-393	-316	-240	-163	-87	-10	66	143
100%	-344	-268	-191	-115	-38	38	115	191
85%	-296	-219	-143	-66	10	87	163	240
3.00								
115%	-340	-263	-187	-110	-34	43	119	196
100%	-298	-222	-145	-69	8	84	161	237
85%	-257	-180	-104	-27	49	126	202	279
2.50								
115%	-287	-210	-134	-57	19	96	172	249
100%	-252	-176	-99	-23	54	130	207	283
85%	-217	-141	-64	12	89	165	242	318
2.00								
115%	-234	-157	-81	-4	72	149	225	302
100%	-206	-129	-53	24	100	177	253	330
85%	-178	-102	-25	51	128	204	281	357

¹All other prices and inputs held at base values.²Steer price only, heifer price discounted \$0.10 per 0.45 kg.

APPENDIX I

Calf crop or weaning percentage may be the single most important measurement of production performance for a cow-calf operation. This is because this measurement effectively evaluates reproduction, which is a major factor in enterprise profitability. Clearly, reproduction in the beef cow is a function of nutrition and calculating calf crop or weaning percentage provides an assessment of the appropriateness of the cowherd nutrition program. Further, the status of the herd health program, animal husbandry, and management can be determined with this measurement. This measurement is extremely useful, because not only does it provide an assessment of the magnitude of calf losses prior to weaning, but it allows one to determine when such losses occur relative to the production cycle. Calf crop or weaning percentage is calculated as $[(\text{number of calves weaned} / \text{number of females exposed for breeding}) \times 100]$. In any cowherd, the breeding female inventory is constantly fluctuating. Therefore, adjustments to the number of exposed females need to be made to account for females entering and exiting the herd. Standardized performance analysis (SPA) is a standardized beef cattle performance analysis system. This system was developed in conjunction with the National Cattlemen's Beef Association (NCBA) and the National Integrated Resource Management (IRM) committees. Essentially, the SPA system facilitates accurate comparisons of performance measures among operations. The SPA system provides standardized adjustments and calculations necessary for calculating calf crop percentage.

Research on intensively managed (confined) cow-calf production systems began at the University of Nebraska-Lincoln in April 2012. That year, an initial group of pregnant females was purchased and transferred to research facilities with calving occurring in summer. The research project's first breeding season subsequently began

during fall 2012. Given that the entire production cycle for determining calf crop percentage begins with the breeding season and ends when that resulting calf crop is subsequently weaned, 2 full production cycles have been completed as of this writing. The first yr production cycle began with the fall 2012 breeding season which produced the calf crop born during summer 2013 which was weaned in February 2014. The second yr production cycle began with the fall 2013 breeding season which generated the calf crop born during summer 2014 which was weaned in April 2015. The following tables (Tables 1 & 2) contain an analysis of calf crop or weaning percentage and calving distribution based on cows exposed by production cycle. Data are combined for Agriculture Research and Development Center (ARDC) and Panhandle Research and Extension Center (PHREC) cowherds as they were considered 1 herd. Calving distribution was determined by calculating the start of the calving season as 285 d after the start of the breeding season. The analysis was done using the guidelines of the SPA Cow-Calf Enterprise Performance Measures Worksheet provided by Texas A&M University Extension (<http://agrisk.tamu.edu/files/2012/07/Spa-1.pdf>). In addition, a summary of all replacement females purchased by the experiment by yr and location as well as information on cows removed from the experiment is presented in Table 3. Table 4 contains calf death loss data by calving season (2012 through 2015) and location and includes cause of death. Contained in this summary is all calf death loss that occurred through weaning for 3 yr (2012, 2013, 2014) and 1 partial year (2015, data reported are current as of September 2015).

Table 1. Standardized performance analysis for yr 1 production cycle data

Reproduction performance measures based on exposed females	%
Pregnancy percentage	90.1
Pregnancy loss percentage	2.6
Calving percentage	87.5
Calf death loss	8.3
Calf crop or weaning percentage	79.2
Female replacement rate percentage	17.7
Cumulative calving distribution	
Calves born during first 21 d	86.0
Calves born during first 42 d	95.0
Calves born during first 63 d	100.0
Calves born after first 63 d	--

Table 2. Standardized performance analysis for yr 2 production cycle data.

Reproduction performance measures based on exposed females	%
Pregnancy percentage	94.9
Pregnancy loss percentage	5.2
Calving percentage	89.7
Calf death loss	13.8
Calf crop or weaning percentage	75.9
Female replacement rate percentage	20.7
Cumulative calving distribution	
Calves born during first 21 d	82.1
Calves born during first 42 d	97.4
Calves born during first 63 d	100.0
Calves born after first 63 d	--

Table 3. Replacement females purchased by yr and location and summary of all females removed from the herd and reason for removal

Item	2012-2013		2013-2014		2014-2015	
	ARDC	PHREC	ARDC	PHREC	ARDC	PHREC
Replacement females, hd ¹	10	7	12	6	23	7
Reason for cow removal ²						
Failed to become pregnant ³	6	1	3	2	2	7
Lost calf ⁴	--	--	1	4	--	1
Disposition	--	1	1	--	1	1
Poor teat/udder	2	1	9	--	4	--
Injury	--	--	--	--	--	--
Death	--	1	--	1	1	1
Bad Eye/Jaw	--	--	--	--	1	--
Total cows removed	8	4	14	7	9	10

¹Represents replacement cows purchased in spring 2013, 2014, or 2015.

²Represents all cows removed during a production yr (i.e. spring 2012 to spring 2013).

³Includes cows either pregnancy checked as open or failed to calve.

⁴Includes calves lost due to abortion.

Table 4. Summary of calf death loss by calving season and location and cause of death

	Abort. ¹	DOA ²	Resp. ³	Scours	Inj. ⁴	Aba. ⁵	Unk. ⁶	Total
2012								
ARDC	--	1	--	--	1	--	1	3
PHREC	--	--	--	--	--	--	--	0
2013								
ARDC	1	1	--	--	--	--	3	5
PHREC	--	2	--	--	--	--	1	3
2014								
ARDC	--	1	--	--	1	--	2	4
PHREC	--	1	1	--	1	--	5	8
2015								
ARDC	--	2	1	--	1	--	1	5
PHREC	--	--	--	--	--	2	2	4
Total	1	8	2	0	4	2	15	32

¹Abort. = abortion²DOA = born dead on arrival³Resp. = respiratory disease⁴Inj. = injury⁵Aba. = abandoned by dam⁶Unk. = unknown

APPENDIX II

Observations regarding intake of different limit-fed diets using various ingredients when fed to mature late-gestation beef cows were made in spring 2014 at the Agricultural Research and Development Center (ARDC) feedlot. The objective was simply to gain information regarding the maximum level that medium to low-quality forages, or the minimum level of distillers that can be fed in limit-fed diets without resulting in ingredient sorting or feed refusal. It is beneficial to understand what inclusion levels are practically optimal for by-products such as distillers grains as well as low-quality forages in limit-fed diets for beef cows because price and availability influence inclusion levels. For the producer, high inclusion levels of forages cause diets to become bulky which increases waste and sorting, and may require multiple feedings in order to deliver a given amount of dry matter. Five different diets were fed to 6 pens of cows (7 cows per pen) over a 25 d period. The sequence of diets fed is illustrated below (Table 1), and diets were formulated to supply an equal energy intake. The following images are bunk readings taken in the morning prior to feeding and illustrate the consumption of diets from the previous day. These observations provide evidence that approximately 80% (DM basis) of either dry or ensiled husklage appears to be the maximum inclusion level that can be fed with distillers grains at an 8.6 kg DMI before sorting and feed refusal occurs.

Table 1. Ingredient composition of diets fed and intakes by date

	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
Ingredient, % DM Basis	5-19	5-22	5-24	6-7	6-13
Ensiled husklage	70.0	80.0	--	--	--
Dry husklage	--	--	60.0	80.0	80.0
MDGS	26.5	16.5	36.5	--	--
DDGS	--	--	--	16.5	--
WDGS	--	--	--	--	16.5
Supplement	3.5	3.5	3.5	3.5	3.5
DMI, kg/cow/d	7.7	8.6	7.3	8.6	8.6
TDN intake, kg/cow/d	5.4	5.4	5.4	5.4	5.4



Figure 1. Diet #1 taken 5-19



Figure 2. Diet #1 taken 5-19



Figure 3. Diet #2 taken 5-22



Figure 4. Diet #2 taken 5-22



Figure 5. Diet #3 taken 5-24



Figure 6. Diet #3 taken 5-24



Figure 7. Diet #4 taken 6-7



Figure 8. Diet #4 taken 6-7



Figure 9. Diet #5 taken 6-13



Figure 10. Diet #5 taken 6-13